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THESIS

THE COST OF MAINTAINING A NAVAL INVENTORY SYSTEM WITH INACCURATE RECORDS

by

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March 2003

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Management of the Naval integrated supply system depends on data to provide reliable information on the quantities of items in stock at any given time. Because of the high volume of transactions that continually alter data in the inventory system, inventory record errors are practically unavoidable. The purpose of this thesis is to determine the effects of inventory data errors on both cost and effectiveness of operations at a Naval inventory site.

The methodology adopted for research consists of a series of multiple-item, single-warehouse, Monte Carlo simulations, focused on one U.S. Navy inventory site, using estimates of inventory data accuracy obtained at that site. Results of the simulations show that inventory costs can be decreased and customer demand effectiveness increased by decreasing the magnitude of inventory record errors to less than ten percent. It is therefore recommended that the Navy expand its inventory accuracy goal to require that no item have an inventory record error magnitude greater than ten percent. Inventory costs and effectiveness in meeting demand for Naval material were not found to be substantially affected by inventory record inaccuracy if the magnitude of error is less than ten percent.

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THE COST OF MAINTAINING A NAVAL INVENTORY SYSTEM WITH INACCURATE RECORDS

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LIST OF ACRONYMS

CNO	Chief of Naval Operation
DOD	Department of Defense
EIA	Estimated Inventory Accuracy
EOQ	Economic Order Quantity
FISC	Fleet Industrial Supply Center
FMSO	Fleet Material Support Office
FY	Fiscal Year
GAO	General Accounting Office
IA	Inventory Accuracy
NAVICP	Naval Inventory Control Point
NAVSUP	Navy Supply Systems Command
SL	Safety Level
STATMAN	Statistical Accuracy Techniques and Measurements Analysis
TVC	Total Variable Cost
UICP	Uniform Inventory Control Program

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EXECUTIVE SUMMARY

Management of a large inventory system depends on data to provide reliable information on the quantities of items in stock at any given time. When the recorded quantity of an item falls below a safety threshold, new material is ordered to replenish the inventory holding of that item. The timing of these orders, and the quantity ordered, are calibrated to ensure that demand for inventory items is met with high probability, and without an excessive investment in material. If inventory levels on record fail to match physical inventory levels, this calibration may fail to promote the efficient inventory management that it was designed to achieve.

The United States Navy maintains a large inventory system, holding more than 400,000 line items valued at $17.5 billion in fiscal year 2000 (Department of Defense, 2000). Management of this inventory is a data-intensive operation in which errors can have highly adverse consequences. The Naval Supply Systems Command (NAVSUP), which oversees the management of the Navy's inventory, has established a goal of 95 percent inventory accuracy for its inventory sites. In order to meet this goal, at least 95 percent of the line items held at an inventory site must achieve a perfect match between the quantity on record and the quantity on the shelf. Establishment of this goal is consistent with the recommendations of the General Accounting Office for federal agencies, based on industry best practices for companies with large inventory systems.

Because its inventory is so large, the Navy cannot know the true inventory levels for all items at all times. In order to estimate inventory accuracy at an inventory site, the Navy takes quarterly random samples of the inventory items that are held at the site, and physically counts the selected inventory items. The percentage of sampled items for which the physical count matches the quantity on record constitutes an unbiased estimate of inventory accuracy at that site.

Inventory accuracy estimates obtained at the 11 Fleet Industrial Supply Center (FISC) San Diego inventory sites during the third quarter of fiscal year 2002 revealed that 8 of the 11 sites failed to meet the NAVSUP inventory accuracy goal for high-demand

items. Failure to maintain high inventory accuracy has the potential to increase inventory costs in two ways. Understatement of the true inventory position can lead to the placement of unnecessary or untimely orders, which increases ordering costs and diverts resources from other needs. It also results in the holding of excessive inventory in the warehouse, which increases holding costs. Conversely, overstatement of the true inventory position increases the likelihood that the inventory system is unable to meet the demand for material when such a demand arises. Failure to satisfy material requirements can impair the effectiveness of Naval activities.

This thesis describes the effects of inventory inaccuracy on both the cost and effectiveness of operations at a Naval inventory site. These effects are analyzed by means of a series of multiple-item, single-warehouse, Monte Carlo simulations, focused on one of the FISC San Diego inventory sites, and using estimates of inventory accuracy obtained at that site. Results of the simulations are used to examine the effectiveness of current Navy inventory accuracy goals and corrective-action policies.

In the first analysis total variable costs (ordering costs plus holding costs) and effectiveness in meeting customer demand over the period of one year were estimated using the most current inventory accuracy estimates at the inventory site. Cost and efficiency were then estimated with inventory accuracy raised to the 95 percent accuracy goal. Results of the analysis indicate that total variable costs were at least 4.8 percent higher and effectiveness 1.3 percent lower for the inventory system operating at its current level of accuracy than at 95 percent accuracy. These estimates are based on conservative assumptions: total variable costs could be as much as 65 percent higher, and effectiveness as much as 6.2 percent lower.

The second analysis attempted to quantify the amount of additional inventory that the inventory site must purchase to compensate for its deficit in customer demand effectiveness, assuming that the inventory site continues to operate at its current level of inventory accuracy. Results of the analysis indicate that the inventory system would require at least an eight percent increase in inventory investment to achieve the same level of effectiveness than if it operated at the 95 percent inventory accuracy goal. The total operating cost for a system is obtained by adding the inventory investment costs to

the total variable costs. For the inventory system under study, total operating costs were at least sixteen percent greater, and possibly as high as seventy-seven percent greater, for the system failing to meet inventory accuracy goals. These results suggest that NAVSUP could decrease operating costs and increase customer demand effectiveness by raising inventory accuracy to the current NAVSUP goal.

The inventory accuracy metric does not fully capture the effect of errors in inventory records on the operation of the inventory system. For example, it does not reflect the size of the discrepancy between the quantity of an item on record and the quantity on the shelf. Current Naval inventory accuracy data contain limited information on the magnitude of discrepancy represented by inventory record errors. Errors are aggregated on a relative basis into four categories: 0 to 1 percent, 1 to 5 percent, 5 to 10 percent, and greater than 10 percent.

An analysis was conducted to measure the effect of varying the magnitude of inventory record errors while holding inventory accuracy at 95 percent for the site under study. In this analysis the percentage of line items with inventory record errors was held constant at 5 percent, and the magnitude of error was systematically increased. Even though the simulated system was operating at the 95 percent inventory accuracy goal, results of the analysis show that total variable costs could be increased by 16 percent and customer demand effectiveness could be decreased by 2 percent by varying the magnitude of error. Inventory costs could be reduced and customer demand effectiveness raised by decreasing the magnitude of error to less than 10 percent across all inventory items regardless of inventory accuracy. These results demonstrate that current inventory data collection techniques could be improved by capturing the actual magnitude of error for those inventory items where the magnitude is greater than 10 percent of the shelf quantity.

Conversely, the thesis research found that reducing inventory accuracy from 95 percent to 67 percent had no discernible effect on customer demand effectiveness or total variable costs if the magnitude of error was less than 10 percent. These results suggest that performing corrective actions to raise inventory accuracy will not have an

appreciable effect on reducing inventory costs or increasing customer demand effectiveness, if the magnitude of error is less than 10 percent.

Results of the thesis research support the following conclusions:

- Inventory costs can be decreased and customer demand effectiveness increased by decreasing the magnitude of inventory record errors to less than 10 percent.
- Inventory costs and customer demand effectiveness are not substantially affected by inventory record inaccuracy when the magnitude of error is less than 10 percent.
- Current inventory data collection techniques should be redesigned to focus on capturing the magnitude of errors for items with inventory records with relative errors greater than 10 percent.

The thesis research also supports the following recommendations:

- Supplement the current 95 percent inventory accuracy goal with the requirement that every line item held at a Naval inventory site achieve a maximum magnitude of inventory error of 10 percent.
- Adopt as policy that all Naval inventory sites satisfy the modified inventory accuracy goal, and that all errors with magnitudes greater than 10 percent be reported to NAVSUP along with current quarterly inventory accuracy reports.

I. INTRODUCTION

The Navy commits substantial resources annually to the procurement of repair parts to support fleet operations. The result is a large inventory system valued at $17.5 billion (DOD, 2000) which is designed to maintain inventory levels at the minimum level needed to ensure operational effectiveness of the Navy. Management of this inventory is a data-intensive operation in which errors have highly adverse consequences. Decisions on how much inventory should be purchased and when to purchase it are based on data that may, or may not, be accurate. Inventory data errors can result in ordering problems that result in having too little material to fill fleet demands, thereby reducing operational effectiveness; or too much inventory, thereby increasing the cost of maintaining it.

Problems caused by data errors in the Navy's inventory systems have long been recognized (Schrady, 1968). However, the Navy remains unaware of the precise costs associated with operating Navy inventory systems with inaccurate inventory records. It is known from inventory theory that as inventory record errors increase, inventory costs increase and that a smaller percentage of customer demands are fulfilled (Tersine, 1998). The purpose of this thesis is to measure the cost of inventory record errors to a Naval inventory system.

In order to accomplish this task, a series of multiple-item, single-warehouse, Monte Carlo simulations of one of the Fleet Industrial Supply Center (FISC) San Diego inventory sites was constructed using inventory theory and actual Naval inventory data. These simulations were designed to facilitate the analysis of inventory errors as they affect inventory costs and material availability. Upon determining the effects of inventory errors on the inventory system, current Naval inventory data collection techniques, inventory goals and corrective action policies are examined.

A. BACKGROUND

Inventory management is critical to achieving the Naval fleet readiness required to support national military strategy (GAO, 2002). However, as early as 1990 the General Accounting Office (GAO) criticized the Navy for having significant readiness and supply problems resulting from the management of its inventory systems, and for procedures that adversely affected the stocking of spare parts (GAO, 2001). GAO made several corrective recommendations to the Navy based on these studies, among which was to improve the accuracy of inventory data records. In order to describe these recommendations, it is important to understand the structure of the integrated Naval supply system, how inventory errors are defined, and how inventory errors are detected.

B. NAVAL INVENTORY MANAGEMENT STRUCTURE

It is the responsibility of the Chief of Naval Operations (CNO) to develop general policy guidelines for the material support of Naval operations. Most of this authority is delegated to the Naval Supply Systems Command (NAVSUP), which reports directly to the CNO. The primary responsibility of NAVSUP is the maintenance of the integrated Navy supply system (NAVSUP, 2000), which is composed of the Naval Inventory Control Point (NAVICP) and six Fleet Industrial Supply Centers (FISCs).

NAVICP exercises centralized control over 400,000 different line items of repair parts, components and assemblies that keep ships, aircraft, and weapons systems operating. NAVICP uses statistical and optimization models to forecast future demand for items based on their demand histories. These models determine the selection and quantity of each item to be stocked at the six FISCs.

Each FISC distributes its inventory stock of repair parts at various FISC partner sites. Partner sites are Navy shore activities that have entered into a partnership with a FISC to form a regional business operation. The purpose of this distribution of material is to place the repair parts in close proximity to the customers.

In April 2000, NAVSUP issued a directive in which Naval shore inventory management policies, procedures, and performance objectives were articulated

(NAVSUP, 2000). Included in this directive are Navy inventory definitions, goals and required corrective actions.

C. GENERATION AND DISCOVERY OF INVENTORY DATA ERRORS

One of the purposes of the NAVSUP (2000) directive is to address the discrepancies created when the inventory quantity on-hand for an item does not match what is thought to be there (record quantity). There is a potential to create an error any time the recorded quantity or the physical quantity of the item is changed. In particular, discrepancies are introduced in the processes of receiving and issuing material, as well as by unauthorized removals of material, or failure to post receipts or issues of material. Additional discrepancies may be generated in adjustments of inventory records for various reasons, including the improper posting of inventory counts, or correctly posting inaccurate inventory counts. Discrepancies may remain unnoticed by the manager for a long period of time, and are not discovered and corrected until a physical inventory of the item is conducted. During this time all decisions centered on when to order and how much to order are based on inaccurate information.

To further discuss the effects of inventory data errors it is convenient to introduce the following terminology:

Line item – A uniquely identifiable item stocked by the Navy supply system. An example of a line item is the rubber gasket for a condensate pump used on a *TICONDEROGA* class ship.

Inventory Accuracy (IA) – The percentage of line items for which there is exact agreement between the quantity in data records and the actual quantity on-hand. To determine the inventory accuracy rate, all line items must be physically counted, and the counts compared to inventory.

Estimated Inventory Accuracy (EIA) – In principle, inventory accuracy is determined by calculating the percentage of inventory line items that have no errors in their record quantities. Due to the size of the Naval inventory system, however, it is impossible to count the inventory holding of every line item regularly. Every quarter each Navy shore inventory site is required to estimate its inventory accuracy and report it

to NAVSUP. Estimation is based on a random sample of line items, which are subjected to a physical inventory count. The sampling methodology used is discussed in Section E of this chapter.

Magnitude of error – The difference between book quantity and on-hand quantity for an inventory item, expressed as a percentage of the book quantity. Magnitude of error does not address whether the error is positive or negative.

Inventory effectiveness – The percentage of customer demands filled by an inventory site relative to the total demands received. NAVSUP (1997) explains the determination of this metric, in which it differentiates between *net effectiveness* and *gross effectiveness.* Gross effectiveness is determined by dividing the number of demands filled by the total number of demands received. It is important to note that gross effectiveness includes all demands whether the line item is stocked at the inventory site or not. Net effectiveness disregards these demands for items that are not stocked at that site by dividing the total number of customer demands filled by the number of demands for stocked items. In this thesis, inventory effectiveness refers to net effectiveness.

Operating Costs – The costs incurred by the inventory system to order and hold stock for a given period time. For the purpose of the thesis the period of time is defined as one year.

D. NAVY INVENTORY ACCURACY GOALS

The Navy has established inventory accuracy goals to ensure the effective operation of its inventory system (NAVSUP, 2000). Since the line items that comprise the Naval supply system vary substantially in price, demand, repair capability, and unit of issue, NAVSUP has stratified its material into the following four categories to better manage inventory accuracy:

- Category A – <u>High Dollar Value</u>. All line items with a unit price greater than $1,000;
- Category B – <u>High Demand and Variability</u>. Items with more than three average quarterly demands or that have an on-hand quantity greater than fifty. Also

included in this category are line items that are issued to customers in peculiar units of issue, such as foot, pound, etc. These items typically have more variability between record quantity and on-hand than other line items due to the increased frequency with which they are handled;

- Category C – <u>Low Maintenance</u>. Line items that have not been inventoried in the past twenty-four months and that have an on-hand quantity less than fifty;
- Category D – <u>All Other</u>. All line items not included in the first three categories.

Current NAVSUP inventory accuracy goals are listed in Table 1 (NAVSUP, 2000). Consistent with the definition of inventory accuracy, these goals are based on the percentage of line items for which the quantity on-hand matches the quantity on-hand record. These goals do not address the magnitude of error for inventory items.

Table 1. U.S. Navy Inventory Accuracy Goals Broken Down by Inventory Category.

Inventory Category	Description	Goal	Tolerance
A	High Dollar Value	99%	0%
B	High Demand/Variability	95%	10%
C	Low Maintenance	95%	5%
D	All Other	95%	5%

Goal is the desired minimum estimated inventory accuracy level based on physical counts of a random sample of inventory items. Tolerance is the amount by which estimated inventory accuracy is allowed to decrease before taking corrective actions is required.

From Table 1 it is seen that the goal for Category B material is 95 percent. Therefore, 95 percent of all Category B line items sampled each quarter must have an exact agreement between record and actual on-hand quantities. The tolerance level reported in Table 1 is used to determine when corrective action is required to increase inventory accuracy. For Category B line items, corrective action must be taken when inventory accuracy falls ten percent below the goal, or at eighty-five percent. At that point all inventory items within the category must be physically counted, and the

inventory records adjusted in an attempt to increase inventory accuracy. However, enforcement of this policy is not uniform and there is no enforcement mechanism for the regional inventory accuracy officer against inventory sites that are not following the policy. Additionally, performance of corrective actions does not ensure that all inventory record errors are corrected. This is due to the possibility of human errors being made during the corrective action process.

In a study of industry practices, GAO examined eighty companies with large inventories that were recognized as leaders in inventory management (GAO, 2002). One of the major recommendations from this study was for all Federal Government facilities to adopt an inventory accuracy goal of at least 95 percent. NAVSUP goals listed in Table 1 are consistent with this GAO recommendation.

E. INVENTORY ACCURACY ESTIMATION

Measurement of inventory accuracy requires a physical count of line items in stock. This is a labor-intensive process that cannot be performed, as a practiced matter, for all line items in the Naval inventory on a continual basis. Instead, the Navy estimates inventory accuracy at each of its inventory sites quarterly by physically counting a random sample of line items. In order to support the estimation of Naval inventory accuracy, NAVSUP commissioned the Fleet Material Support Office (FMSO) to develop a multi-purpose statistical analysis tool, known as Statistical Accuracy Techniques and Measurements Analysis (STATMAN). STATMAN takes from 4 to 449 parameter inputs from the inventory site depending upon the level of inventory stratification desired. FMSO (1994) describes these inputs and NAVSUP (2000) lists the required inventory site inputs. These inputs are then used to stratify the entire set of inventory records maintained by the inventory site into categories. STATMAN determines the required sample size for each substratum category using the following formula (FMSO, 1991):

$$n = \frac{Np(1-p)}{(N-1)(B/Z_\alpha)^2 + p(1-p)} \qquad \textbf{(1)}$$

where:

n = sample size

N = population size (number of line items in category)

p = estimated accuracy

B = bound of error

Z_α = standard normal quantile corresponding to confidence level $1-\alpha$

The user inputs population size, estimated accuracy, bound of error and the confidence level. The estimated accuracy and confidence level have a maximum value of 0.95 and a default value of 0.95. Bound of error has a maximum value of 0.04, with a default value of 0.02. However, the sample size being calculated by equation 1 can be overridden by setting the maximum value of n to a predetermined value.

Line items to be physically counted are randomly selected using a random number generator to give the desired sample size. After the sampled items have been physically counted, the results are entered into STATMAN, which is then used to calculate estimates of inventory accuracy.

In addition to estimates of inventory accuracy, STATMAN provides estimates of the magnitude of inventory data errors, broken down into five intervals: (1) no error (0 percent), (2) greater than 0 percent but less than 1 percent, (3) greater than or equal to 1 percent but less than 5 percent, (4) greater than or equal to 5 percent but less than 10 percent, and (5) greater than or equal to 10 percent. This is illustrated in Table 2, which is a portion of a STATMAN summary report for the eleven FISC-San Diego inventory partnership sites for the third quarter of 2002, pertaining to Category B line items. The names of these sites are not included in this thesis due to an A-76 cost comparison study currently being conducted.

The columns of Table 2 give cumulative percentages; for example, 92.31 percent of sampled line items at Site 1 had no inventory errors, 2.56 (94.87–92.31) had inventory

errors in the 0–1 percent range, and there were no items with errors greater than 5 percent.

Table 2. Estimated Magnitude of Inventory Record Errors for Category B Material at Eleven FISC San Diego Partnership Inventory Sites, Third Quarter 2002

Site	Magnitude of Inventory Record Error (Percent of Physical Count) 0 %	≤ 1%	≤ 5 %	≤10 %	>10 %	Total line items	Line items sampled
1	92.31	94.87	100.00	100.00	0.00	347	39
2	70.13	74.03	79.22	80.52	19.48	2169	77
3	93.18	95.45	95.45	97.73	2.27	1068	44
4	85.42	89.58	91.67	95.83	4.17	5047	48
5	91.89	94.59	100.00	100.00	0.00	487	37
6	88.64	90.91	95.45	95.45	4.55	1221	44
7	100.00	100.00	100.00	100.00	0.00	2021	44
8	67.31	67.31	76.92	76.92	23.08	322	52
9	100.00	100.00	100.00	100.00	0.00	825	49
10	100.00	100.00	100.00	100.00	0.00	639	43
11	94.44	94.44	94.44	94.44	5.56	175	18

Inventory accuracy percentages at the partnership sites are shown in the second column (0 % Magnitude of Error).

In Table 2, it is seen that six of the FISC-San Diego sites had at least one sampled line item with an inventory data error greater than ten percent. For example, Site 11 had 5.56 (100–94.44) percent of sampled line items with a magnitude of error greater than ten percent. It is important to note that the actual magnitudes of error for these items could be anything larger than ten percent.

Examining the percentage of items with zero percent magnitude of error, it is seen that eight of the eleven FISC San Diego partnership sites failed to meet the NAVSUP inventory accuracy goal during the third quarter of 2002. Similar finding were observed across several quarters for which inventory accuracy reports were examined. Sites 2, 4 and 8 have failed to meet the goals every quarter from 2002 Quarter 1 through 2002 Quarter 4. It is clear from these reports that the Navy's inventory goals are not being met on a consistent basis and that the corrective action policies are either not correctly being conducted, or that they are ineffective in controlling inventory accuracy.

F. PREVIOUS WORK ON NAVAL INVENTORY ACCURACY

Errors in inventory records have long been recognized as a problem in the Navy. Schrady (1968) recognized the seriousness of the problem with his statement that

> Inventory record accuracy is currently the number one problem confronting NAVSUP (p. 23).

More than thirty years later the Navy's inventory record accuracy was again the focus of criticism (GAO 2001). And, as noted in the previous section of this thesis, inventory accuracy shortfalls have persisted to the present time.

Schrady (1968) recognized the importance of inventory record accuracy due to its ultimate effect on demand effectiveness, and he recognized that the central problem in inventory record accuracy was to determine the cost of operating an inventory system with inaccurate stock records. The Masters thesis of Daeschner (1968) attempted to address the latter problem. Daeschner constructed a Monte Carlo simulation of daily inventory operations that was programmed in FORTRAN. Two separate inventory quantities were maintained over time to represent the actual quantity and the record quantity. Demand quantities were randomly generated from geometric distributions, and times between demands were randomly generated from exponential distributions. Issues were made upon receipt of demands, and reordering of stock was based on the record quantity. Inventory errors were introduced into the model by randomly perturbing the quantity that was issued or received. These discrepancies were the sources of errors that eventually were manifested in the inventory records. As errors accumulated, inventory accuracy decreased. Using this technique, Daeschner found that inventory record

accuracy decreased an average of 10.4 percent per year over the five-year time-span of his study. Daeschner linked this decrease in accuracy to increased operating costs. However, Daeschner did not consider how varying inventory accuracy affected these costs.

Daeschner's research provided a framework for analyzing the effects of inventory record errors, and he recommended further studies concerning the cost of operating an inventory system with inaccurate records. However, to the author's knowledge, no such studies have followed.

G. THESIS OBJECTIVE

The objective of this thesis is to develop a methodology to determine the cost of operating a multiple-item, single-warehouse inventory system with inaccurate records. Daeschner's model was run on 50 line items that were identified by NAVSUP as having the greatest procurement expenditure in the previous year. In contrast, this thesis uses actual inventory accuracy data from an entire category of line items from a FISC San Diego partnership site. This approach will determine potential savings that could be realized if inventory accuracy were increased, and provides the methodology to analyze any category of material stocked by the Navy.

The approach adopted in this thesis is similar to Daeschner's in that it uses simulation to measure the effects of inventory record errors. However, a different approach is used in modeling these errors. Under Daeschner's model the introduction of random inventory data errors progressively worsened inventory record accuracy over time. It should be noted, however, that such worsening does not describe the typical behavior of Naval inventory systems operating under current policies. In fact, four of the eleven inventory sites at FISC San Diego had increasing inventory accuracy for Category B material, across the four quarters of fiscal year 2002. Daeschner's study underestimated the effects of corrective actions being taken to increase inventory accuracy. In his thesis, Daeschner showed a 10.4 percent decrease per annum in inventory accuracy. Inventory accuracy data for the eleven FISC San Diego inventory

sites revealed this number to be only a 1.05 percent decrease in inventory accuracy in fiscal year 2002.

In this thesis it is assumed that inventory accuracy remains constant over a one-year period of time. This assumption allows inventory record errors to be introduced at the beginning of the simulation, and to remain there for the duration of the study. This approach permits detailed analyses of the effects that varying inventory accuracy has on a Navy inventory system's operating costs and demand effectiveness.

H. ORGANIZATION OF THE THESIS

The remainder of this thesis is organized as follows. Chapter II reviews current literature addressing the effects of inventory errors on inventory management, discusses inventory management theory, and then looks into current Navy forecasting models to determine the impact that these errors have on Navy inventory systems. Chapter III outlines current Navy inventory management policies and processes and presents the methodology used to construct the model that will be used in this thesis to simulate the operation of the current Navy inventory system. Chapter III is concluded by presenting the collection and determination of the data that was used in the model. Chapter IV presents the analysis of how inventory accuracy affects operating costs and demand effectiveness and discusses the financial impact that decreased demand effectiveness has on operating costs. The effects of magnitude of error on operating costs and demand effectiveness are then observed to evaluate current inventory accuracy goal completeness. And finally, current inventory data collection techniques and corrective action policies are examined to determine their ability to control the negative effects of inventory errors. Chapter V concludes by presenting conclusions and recommendations for inventory accuracy goals, corrective actions, and data collection techniques.

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II. THE NAVAL INTEGRATED SUPPLY SYSTEM

Accurate and reliable data are essential to an efficient and effective operating environment in the private sector as well as in the federal government. Inventory represents a significant portion of the assets of both the federal government and private companies. Therefore, managers and other decision-makers need to know how much inventory there is and where it is located in order to make effective budgeting, operating, and financial decisions and to create a government that works better and costs less to operate (GAO, 2002).

Inventory inaccuracies prevent the inventory system from knowing the precise on-hand quantity of each line item. As a result, material may be ordered at a time that is different from the optimal reorder point, thereby causing the system to perform at a sub-optimal level. If inventory records indicate more stock than is actually present, reordering may be delayed, which increases the risk of running out, thereby potentially lowering the inventory system's demand effectiveness.

Most of the current studies being conducted on the effects of inventory data errors are being accomplished in the private sector. An analysis of these studies show that the Navy inventory data errors are similar to the private sector, and therefore they have applicability in this thesis.

A. INVENTORY ACCURACY ANALYSIS IN THE PRIVATE SECTOR

Inventory experts have shown that for an inventory system to work efficiently the data upon which it is based must be accurate (Tersine 1998). Erroneous data can propagate errors throughout the management operations of an inventory system. Titmuss (2001) has conducted stores and stock control educational training at private companies since 1993. From his experience, Titmuss estimates that eighty percent of supply chain management problems could be traced to inventory records that are not accurate. Titmuss identified the following consequences of inaccurate inventory data:

- Material shortages
- Material excesses
- High freight costs
- Excessive expediting
- Lost sales and lost customers
- Missed schedules
- Late deliveries

In the private sector, inventory record errors manifest themselves as lost profit. In a study of 35 leading retailers, Raman (2001) made the following observation:

> The executives at one company with a reputation for expert data handling estimated that their data were "99% accurate". Physical audits, however, showed that inventory levels were way off the mark for two-thirds of the stores' stock-keeping units, or SKUs. We estimate that those errors reduced the company's overall profits by 10% through unnecessary inventory carrying costs and lost sales from out-of-stock items. (p. 2)

Some might argue that the Navy is not concerned with such business concepts as profit, because its mission is national defense. But even as a non-profit enterprise, the Navy has an interest in achieving its objectives in an environment where it must compete with other defense and governmental activities for resources. To do so, the Navy must manage its inventory resources as efficiently as possible.

B. INVENTORY THEORY

During the early 1960s NAVICP developed the Uniform Inventory Control Program (UICP) model based primarily on the inventory theory of Hadley and Whitin (1963). This theory is outlined in NAVSUP (1992), which gives a detailed derivation of the models used in UICP. All FISC line items are stocked according to this model.

The following definitions are introduced to aid in the explanation of inventory-theory concepts that are relevant to the thesis research:

Inventory position: The actual inventory on-hand plus material on order for a specific line item.

Reorder point: The inventory position at which a reorder for material is made for a specific line item. The reorder point is often referred to as "when to order".

Reorder level: The quantity of material to be ordered for a specific line item. The reorder level is often referred to as "how much to order" or "reorder quantity".

Holding costs: The costs of holding inventory for a given period of time. This cost is based on opportunity costs, obsolescence costs, and pilferage costs. The Navy combines these factors into a holding cost rate of twenty-three percent, per year. The holding cost rate is then multiplied by the unit price of the item to determine the cost to hold that unit as inventory for a year. Subsequently, the holding costs for a Navy inventory system is the summation of holding costs for all inventory line items held during that year.

Ordering costs: The administrative costs incurred by ordering material to replace stocked inventory for a given period of time. The ordering costs are obtained by multiplying the total number of orders made over a period of time by the cost to make one order. This study assumes the cost to make one order to be one hundred dollars and the period of time to be

one year (Department of Defense, 1970).

Backorder costs: The costs incurred by allowing material to be backordered, or filled at a later date.

Lead time: The time between ordering material and receiving it.

Level of service: The percentage of customer demands that NAVICP wishes to fulfill.

These definitions are the basis for constructing the UICP inventory model, and subsequently the model to be used in this thesis. The following seven assumptions underlie the development of this model:

1. There exists a continuous review system where NAVICP demands and actual on-hand quantities are known at all times.
2. There exists a steady state environment, in which mean demand and lead times, although variable, remain stationary over time.
3. An order is placed once the reorder point is reached and the entire order is received at the same time. This reorder level is positive. The reorder quantity is constant. There are no budgetary limitations, so the entire order quantity can be procured.
4. Backorder and shortage costs are known and can be quantified.
5. Units of inventory items are demanded one at a time.
6. The cost of an order is constant and is independent of order quantity.
7. Demands are either filled or backordered. There are no lost sales.

Based on these assumptions a number of important aspects of Naval inventory system operations can be described mathematically. The objective of Naval inventory system management is to minimize total costs while achieving required effectiveness in meeting demand. For this mathematical formulation it is assumed that all demands will be filled. Under this assumption the quantity of each line item required for that year is known, and the cost of purchasing this inventory is constant. As a result, the only

remaining costs are ordering costs, holding costs, and backorder costs. The sum of these three costs is referred to as the Total Variable Cost (TVC). Since requisitions cannot be held at a FISC until material is received, there are no backorder costs, which reduces TVC to the sum of the annual ordering cost and the annual holding cost.

In the UICP model, TVC is formally determined using the following formula:

$$TVC = 4\frac{DA}{Q} + IC\left(\frac{Q+1}{2} + B - DL\right) \tag{2}$$

where,

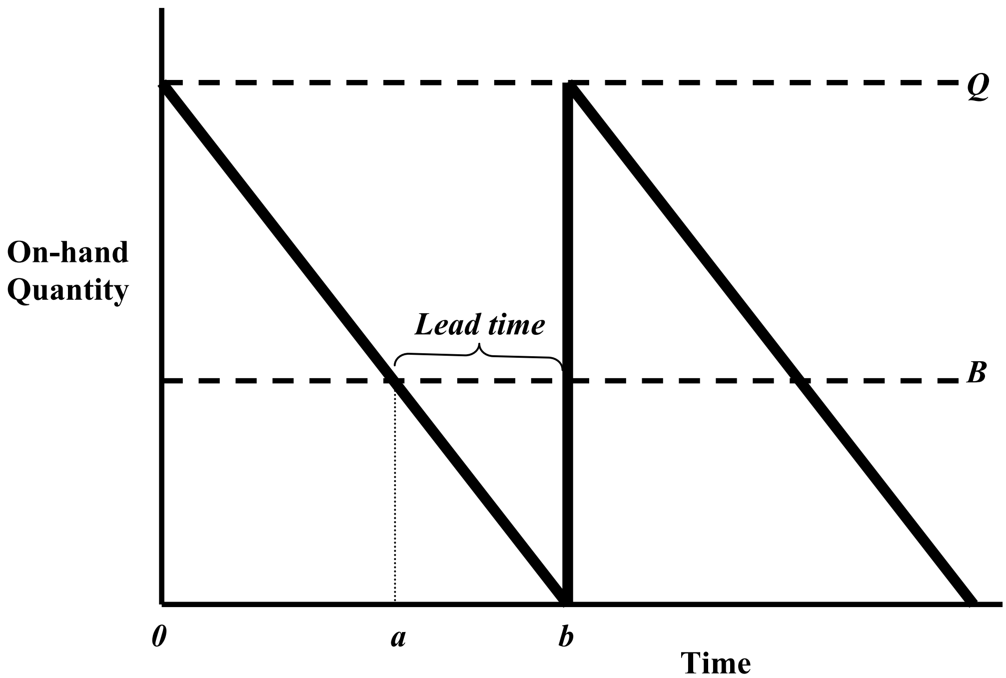
TVC	=	Total annual variable cost
D	=	Quarterly demand
A	=	Order cost
Q	=	Order quantity
I	=	Holding cost rate
C	=	Unit cost
B	=	Reorder level
L	=	Leadtime

The value of Q that minimizes TVC is referred to as the economic order quantity (EOQ), referenced by the symbol Q^*. To find Q^* the partial derivative of equation (2) with respect to Q is set equal to zero, which yields the following solution:

$$Q^* = \sqrt{\frac{8DA}{IC}} \tag{3}$$

Since annual demand is assumed to be known and constant, the optimal reorder level (Q^*) can also be determined. This is done by examining the classical economic order quantity model (Tersine, 1998) shown in Figure 1.

Figure 1. On-hand Quantity over Time for Constant Demand



In Figure 1 the on-hand quantity at time zero is equal to Q. The on-hand quantity steadily decreases at a known constant rate since the demand rate is constant. To ensure that the on-hand quantity does not reach zero, an order must be placed before that happens, at time b. To minimize holding costs the order must arrive at the same time that the on-hand quantity reaches zero. Since the order lead time (L) is assumed to be known and constant, the order should be placed at time $a = b - L$. Conversely, the optimal reorder point a is the time at which the on-hand quantity is equal to B. Therefore, the total variable costs for this item are minimized if Q^* units are ordered every time the on-hand position reaches B. For this model $Q = Q^*$.

The classical EOQ model shown in Figure 1 is based on the assumption that the demand rate is known, constant and continuous. For practical purposes, the model must be adjusted slightly to take into consideration the stochastic nature of demand.

Figure 2. On-hand Quantity over Time for Variable Demand Rate

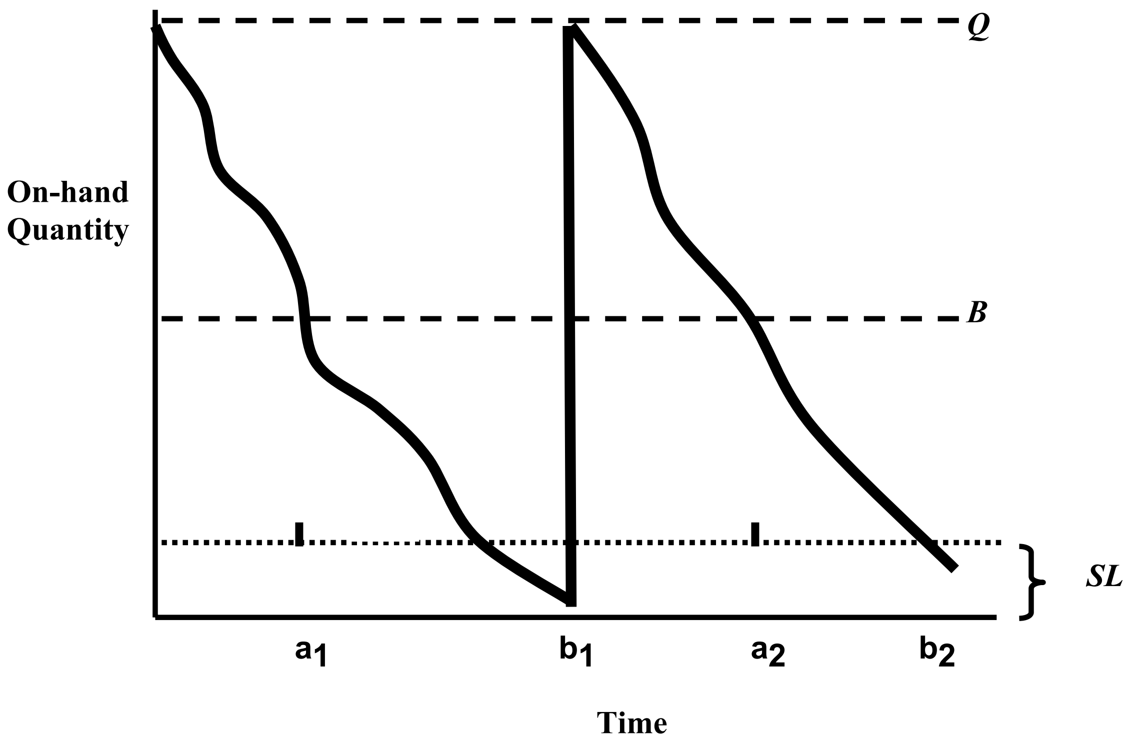


Figure 2 provides an illustration of a model with an actual demand rate that is not constant. From this figure we can see that reorders should be placed at times a_1 and a_2. However, due to the variable demand rate the actual number of demands that will occur before the orders are received is unknown. Therefore, a safety level (SL) is introduced to ensure that the on-hand quantity has a reasonable probability of not reaching zero.

In the UICP model the safety level is modeled as a function of demand variability, procurement lead time variability and the desired level of service. Therefore, the reorder point quantity must increase by the same value as the safety level:

$$B_{new} = B_{old} + SL \quad \textbf{(4)}$$

Due to variability of demand and procurement lead time it is possible for an order to be outstanding when the reorder point is reached again. To prevent the placement of an unnecessary order, the reorder point is based on the Inventory Position which is defined as follows:

$$\text{Inventory Position} = \text{Inventory On Hand} + \text{Inventory On Order} \qquad \textbf{(5)}$$

From this formulation each line item held in the Navy inventory system is assigned a reorder point and reorder quantity based on their previous demand history, lead time, and desired service level.

C. INVENTORY RECORD ERROR CLASSIFICATION

To study inventory record errors it is useful to descriptively categorize inventory record inaccuracies. The following terms will be used to facilitate the discussion:

Book quantity: The quantity of an inventory item obtained from inventory records.

Shelf quantity: The quantity of an inventory item physically present in an inventory facility.

Zero error: A condition where the shelf quantity is equal to the book quantity.

Positive error: A condition where the shelf quantity is greater than the book quantity.

Negative error: A condition where the shelf quantity is less than the book quantity.

In Section E of Chapter I, it was explained that inventory accuracy is estimated by the Navy on a quarterly basis, based on the shelf quantities of randomly sampled items. Shelf quantities are then compared to book quantities to determine if an inventory record error exists. For a category of items, inventory accuracy is estimated as the percentage of sampled items where the book and shelf quantities are in agreement:

$$Inventory\ accuracy = \frac{number\ of\ Zero-error\ sampled\ line\ items}{number\ of\ line\ items\ sampled} \times 100\% \qquad \textbf{(6)}$$

This metric is the basis for current NAVSUP inventory goals and corrective action policies. However, it fails to account either for the magnitude of error or the fiscal impact of inventory data errors. Schrady (1968) recommends using magnitude of error as a metric for inventory record accuracy. Magnitude of error is calculated as follows.

$$Magnitude\ of\ error = \left|\frac{book\ quantity - shelf\ quantity}{book\ quantity}\right| \quad \textbf{(7)}$$

Inventory errors can also be measured based on the monetary adjustment that must be made. This metric can be useful for describing financial impacts associated with inventory record errors. A straightforward definition of this monetary cost is given as follows:

$$Monetary\ adjustment = |book\ quantity - shelf\ quantity| \times unit\ price \quad \textbf{(8)}$$

STATMAN uses equation (8) to determine the monetary adjustment for each line item. The percentage of line items within a given category of monetary value of error are then determined and reported as the dollar adjustments gross (percentage) in its quarterly reports.

D. IMPACT OF INVENTORY RECORD INACCURACIES ON THE UICP MODEL

In theory, if the economic order quantity (Q^*) is ordered when the inventory position reaches the reorder point (B), the inventory system will perform at the desired service level while operating at the lowest overall cost. The UICP model tries to maximize the service level while minimizing operating costs. Any introduction of data errors will affect this calculation. This problem is illustrated in Figures 3 and 4.

Figure 3. On-hand Quantity over Time with Negative Error

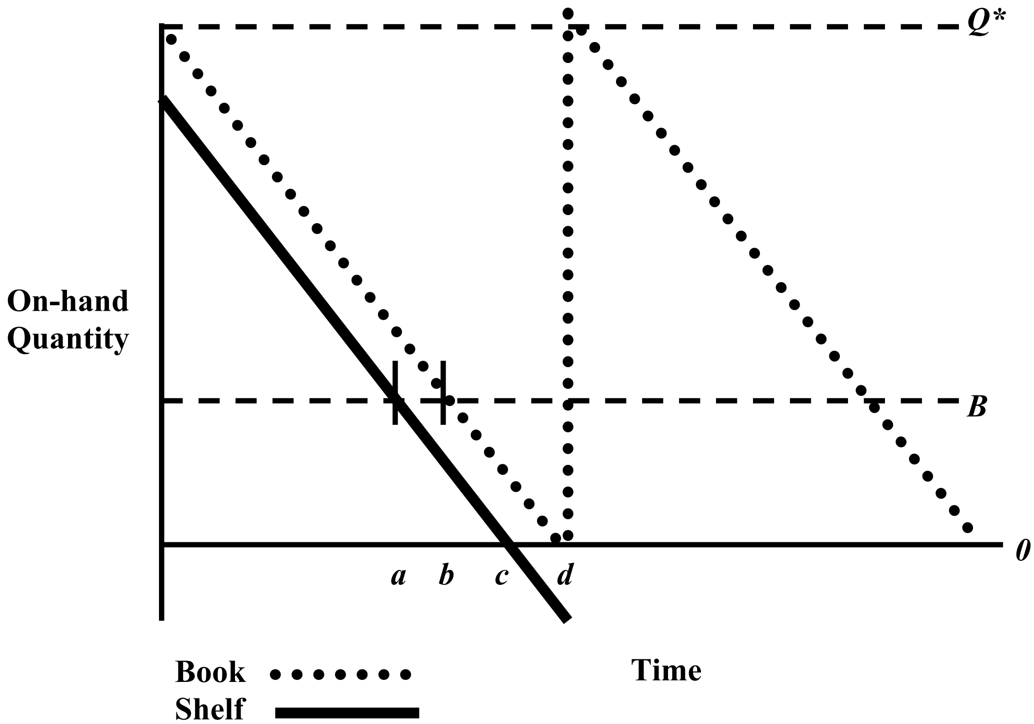
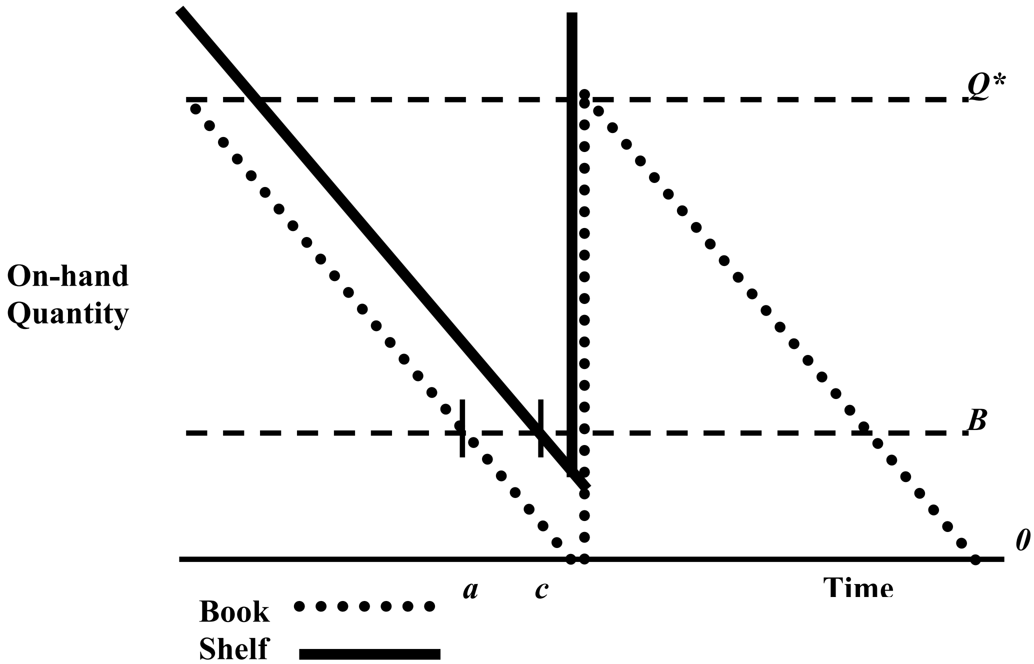


Figure 3 demonstrates the effect that negative error has on the inventory system over time. Inventory theory proposes that the optimal reorder point (*B)* occur at time *a.* However, the order will not be placed until time *b*, reflecting the fact that the reorder point is based on the book quantity instead of the shelf quantity. In a system with constant demand and no safety level, the shelf quantity will reach zero at time *c* and all customer demands received from time *c* until time *d* will not be filled. In the UICP model with variable demand and safety level there exists a chance that the system will run out of material before the reorder quantity is received. In either of these scenarios, every customer demand that is not filled reduces the demand effectiveness of the inventory system in meeting demand.

Figure 4. On-hand Quantity over Time with Positive Error



Conversely, Figure 4 illustrates a positive error and the effects that a positive error may have over time. The optimal reorder point for this example is at time c. However, an order is prematurely placed at time a causing the order to arrive early and the optimal reorder quantity (Q^*) to be exceeded. Ordering too early can lead to suboptimal operation by causing the inventory system to hold an excessive quantity of material. Inventory holding costs increase in direct proportion to the proportion of positive error, because it is a function of the average number of units on hand (Tersine, 1998). Private enterprises are regularly concerned with the opportunity cost associated with ordering and holding the wrong material. Because the Department of Defense includes opportunity cost in the holding cost equation (DOD, 1970), it will not be considered further in this thesis.

In summary, if an inventory system has more positive errors than negative errors, it will have a tendency to hold more material than is necessary to meet demand, which in turn will increase holding costs. Conversely, if there are more negative errors than positive errors, the system will have a tendency to encounter situations where demand

cannot be met from inventory, and its demand effectiveness will decrease. Inventory record errors, whether positive or negative, have greater detrimental effects as their magnitude increases.

It is clear that inventory record errors can affect a range of inventory management operations. In order to analyze these effects in a Naval inventory system, it is useful to model the operation of the inventory system over a fixed period of time both with and without inventory record errors. In Chapter III a model for a Naval inventory site is described and used in a simulation study to measure the effects of inventory record errors.

III. DATA USED IN RESEARCH

The purpose of inventory system analysis is to describe the essential features of the system's operation. An important tool in the analysis of the Naval inventory model is the baseline data (Tersine, 1998). This chapter describes the data that were used in the analyses described in this thesis. Actual operating data for all high-demand items held at FISC San Diego Site 8 is provided as the basis for the inventory model that was used in simulation studies. These data consist of inventory accuracy reports obtained for the chosen inventory site during fiscal year 2002.

A. FOCUS OF DATA COLLECTION

Inventory Accuracy Statistics Reports (U152G) were obtained for all eleven FISC San Diego partnership sites in each of the four quarters of fiscal year 2002. A summary of information from the Third Quarter (FY 2002) report was provided in Table 2 (Chapter I).

Eight of the sites listed in Table 2 failed to meet the NAVSUP inventory accuracy goal of 95 percent for high-demand (Category B) material. However, Site 8 was chosen for analysis due to its consistent inability to meet the NAVSUP inventory accuracy goals. Focusing on this site provides the clearest demonstration of the incremental benefits that can be gained when inventory record accuracy is gradually improved.

The decision was made to focus on Category B material, because low-demand items typically have insufficient inventory activity to show all of the effects of inventory record errors over short periods of time. Although low-demand items can experience measurable increases in holding costs due to inventory record errors even over short time periods, high-demand items are more broadly affected. Furthermore, high-demand items have a greater impact on inventory activity. For example, at one of the FISC San Diego inventory sites 16.8 percent of the line items held were Category B material, but these items accounted for 38.9 percent of the demands received, and 39.6 percent of the orders placed during the first two quarters of fiscal year 2002. At Site 8, a total of 337 line items were identified as Category B material on 12 November 2002. Due to the constant

changes in demand, it is possible for an item to migrate from one inventory category to another. It is therefore feasible that the number of line items in a category change over time.

The following information was obtained for each of the 337 line items from databases access through the Fleet Material Support Office (FMSO) website (https:\\inform21.fmso.navy.mil/cognos):

1. Annual demand
2. Order cost
3. Order quantity
4. Unit cost
5. Reorder level
6. Procurement lead time

B. INVENTORY ACCURACY DATA

Data on inventory record accuracy for Site 8 was obtained from the Inventory Accuracy Statistics Report (U152G) for the second quarter of fiscal year 2002. This report indicates that a random sample of 52 of the 322 Category B line items was taken in order to obtain estimates. Of the 52 line items sampled, 35 (67.31 %) had no errors, 5 (9.61 %) had magnitudes of error ranging from 1 and 5 percent, and 12 (23.08%) had magnitudes of error greater than 10 percent. These results were used as parameters to the simulation study.

System simulation is also dependent upon the proportion of inventory record errors that are positive and negative. All eleven FISC San Diego partnership sites' third quarter 2002 Inventory Accuracy Statistics Report (U152G) were analyzed to determine these proportions for Category B material located at the collective sites. There were 61 total Category B errors for all sites. Of this total, 24 were positive and 37 were negative. Therefore, the proportion of errors that were positive was 0.393; and 0.607 were negative. Based on this finding, proportions of 0.4 and 0.6 for positive and negative errors respectively were used as parameters to the simulation study.

IV. RESULTS OF THE ANALYSIS

Inventory systems have operating rules that are periodically applied to the individual line items. Each day demands are received, orders are placed for items that meet reorder criteria, and orders are received. As these transactions occur, inventory records are updated, and the actual quantities of line items in stock are changed. In designing a simulation of an inventory system, its operation in real time must be emulated. Part of the thesis research was to design a multiple item, single warehouse, Monte Carlo simulation based on the FISC San Diego inventory site that was selected according to the criteria presented in Chapter III. By operating the simulated inventory system with error-prone records over the course of one year, it was possible to estimate the costs associated with inventory record errors. This technique allows artificial but realistic sequences of events to be observed (Tersine, 1998).

A series of simulations was conducted on the 337 high-demand inventory items held at FISC San Diego Site 8 to address inventory system performance issues from the different perspectives listed below.

Simulation Set	Description of Analysis	Section
1	Varying inventory accuracy effects on demand effectiveness and total variable cost	B
2	Varying inventory accuracy effects on inventory costs and total operating cost	C
3	Varying magnitude of error effects on demand effectiveness and total variable cost	D
4	Evaluation of current inventory accuracy goals	E
5	Evaluation of current inventory accuracy policy	F
6	Varying proportion of positive/negative error effects on demand effectiveness and total variable cost	G

A. MODEL DESCRIPTION

Prior to developing the simulation model it was important to acquire an understanding of the inventory system at the FISC San Diego partnership site that served as its basis. The ongoing process in which requisitions are filled and orders for new material placed can be described as follows:

1. When a requisition for material arrives at the inventory site, its database is queried to determine the book quantity. If the record indicates a positive quantity at the warehouse an employee is dispatched to the item location. Once collected the item is prepared for shipment. The quantity on record for the item is then decreased by the quantity shipped. In the event of a partial fulfillment of the demand, the remaining unfilled demand is then forwarded to NAVICP.

2. If the record indicates no material, or if no material is found in stock, the requisition is forwarded to NAVICP for disposition, and the quantity on record is set to zero.

3. Each demand for a stocked item that arrives increases the total demands for that item for the given period. If the item is subsequently filled, the number of demands filled increases. If the item is not filled the number of demands filled remains the same.

4. Upon the conclusion of the business day all inventory items are queried to determine if they are at or below their reorder points. Orders are placed for items that meet the reorder criterion, at their respective reorder quantities.

5. Material that had been ordered previously arrives throughout the business day. Upon receipt of this material, the book quantity is increased by the indicated amount, and the material is stowed in the proper location.

The simulation model followed these steps on a day-by-day basis over the course of one year, using randomized inventory record errors and randomized demands. The computer code for this simulation model, titled InventoryModel.java, is reproduced in Appendix A.

The following assumptions concerning the operation of the inventory system were adopted:

A1. Requisitions (demands) for an item over the course of a 365-day year arrive at the inventory site according to a Poisson process (Hadley, 1963) with annualized rate equal to its forecast demand. There are no weekend or holiday effects.

A2. Each demand is for a quantity of one.

A3. If a requisition is received but either the book or shelf quantity for that item is zero, the requisition is referred outside of the inventory site. Total demand increases by one and the number of demands filled remains unchanged. The book quantity is set to zero, and the shelf quantity remains unchanged. The inventory position remains unchanged.

A4. If a requisition is received and both the book and shelf quantities are greater than zero, the requisition is filled. Total demand and the number of demands filled both increase by one. Both the book and shelf quantities, and the inventory position, are decreased by one.

A5. At the end of each day orders for new material are placed for those items with inventory positions at or below their reorder points. The inventory positions of these items are increased by their respective reorder levels.

A6. Procurement lead-time for orders is deterministic, but varies by item.

A7. Orders arrive at the beginning of the day, before any requisitions are processed. Both the book and shelf quantities are increased by the reorder level, and the inventory position remains unchanged.

A8. Each order that is placed increases the total number of orders by one.

A9. Holding costs are accumulated at the end of each day by multiplying the shelf quantity of each item both by its unit cost and by a daily holding cost rate of .000575 (DOD, 1970).

Initial book quantities, unit costs, annual demand forecasts, reorder points, reorder quantities, and procurement lead-times used in the analysis were obtained from the FMSO InforM21 website (https:\\inform21.fmso.navy.mil/cognos) on 12 November 2002.

For conducting the simulations, the following assumptions concerning the introduction of inventory record errors were also made:

R1. At the beginning of the year, the initial shelf quantity for each inventory item is treated as a random variable with a probability distribution chosen to reflect the inventory record accuracy data at the inventory site.

R2. No additional random errors are introduced during the year to the shelf quantities. Changes to book and shelf quantities, and to inventory positions, made in response to requisitions filled and orders received are assumed to be accurate.

A separate computer program was written to randomly draw initial shelf quantities based on the absolute relative error and the percent positive/negative relative errors chosen for the simulation. The JAVA code for this program, titled ShelfGenerator.java, is reproduced in Appendix A. Perturbing the shelf quantity accurately is important in order to properly emulate the operation of the inventory site. ShelfGenerator accomplishes this in a three-step process using absolute relative errors and proportions of positive and negative errors obtained from STATMAN reports for the second quarter of fiscal year 2002:

1. Generate a uniform (0,1) random number u and compare it to a look-up table derived from the magnitudes of error reported by STATMAN. The format of the look-up table is shown in Table 3. The value of k between 1 and 5 is assigned for which the following inequality statement is satisfied:

$$P_{k-1} < u \le P_k$$

where $P_0 \equiv 0$. For FISC San Diego Inventory Site 8, the following values were used: $P_0 = 0,\ P_1 = P_2 = .6731,\ P_3 = P_4 = .7692,\ P_5 = 1$. Equivalently, this rule assigns the following probabilities to *k*: $p_1 = .6731,\ p_2 = 0,\ p_3 = .0961,$ $p_4 = 0,\ p_5 = .2308.$

Table 3. Magnitude of Error Determination

k	Error Magnitude Interval	Proportion Of Items	Cumulative Proportion
1	Error $= 0\,\%$	p_1	$P_1 = p_1$
2	$0\,\% < \text{Error} \leq 1\,\%$	p_2	$P_2 = P_1 + p_2$
3	$1\,\% < \text{Error} \leq 5\,\%$	p_3	$P_3 = P_2 + p_3$
4	$5\,\% < \text{Error} \leq 10\,\%$	p_4	$P_4 = P_3 + p_4$
5	$\text{Error} > 10\,\%$	p_5	$P_5 \equiv 1$

For example, if *u* = .7211, then *k* = 3, and the absolute difference between the shelf and book quantities is between one and five percent of the book quantity.

2. If *k* = 2, 3, or 4, generate a random number, *v*, that is uniformly distributed in the error interval corresponding to the value of *k* determined in Step 1. If *k* = 1, then *v* = 0, and if *k* = 5 then *v* = .10.

3. Let p_{NEG} denote the proportion of inventory items that have negative errors (shelf quantity less than book quantity), obtained from the STATMAN reports. Generate uniform random variable *w*. If *w* is less than or equal to p_{NEG}, the initial shelf quantity is 1 – *v* times the book quantity; otherwise, the initial shelf quantity is 1 + *v* times the book quantity. For FISC San Diego Inventory Site 8, the value $p_{\text{NEG}} = 0.6$ was used.

For each simulation of the inventory system, ShelfGenerator was used to set the initial shelf quantity for each item. The inventory system was then run for the period of one year, with randomly occurring demands, in a manner consistent with assumptions A1 through A9. This process was repeated 1,000 times, which provided data from which mean cost and effectiveness metrics were determined. Specifically, the following metrics were obtained:

- Demand Effectiveness
    - Total demands
    - Demands filled
- Holding Costs
    - Daily shelf quantity
- Ordering Costs
    - Total orders

B. EFFECTS OF VARYING INVENTORY ACCURACY

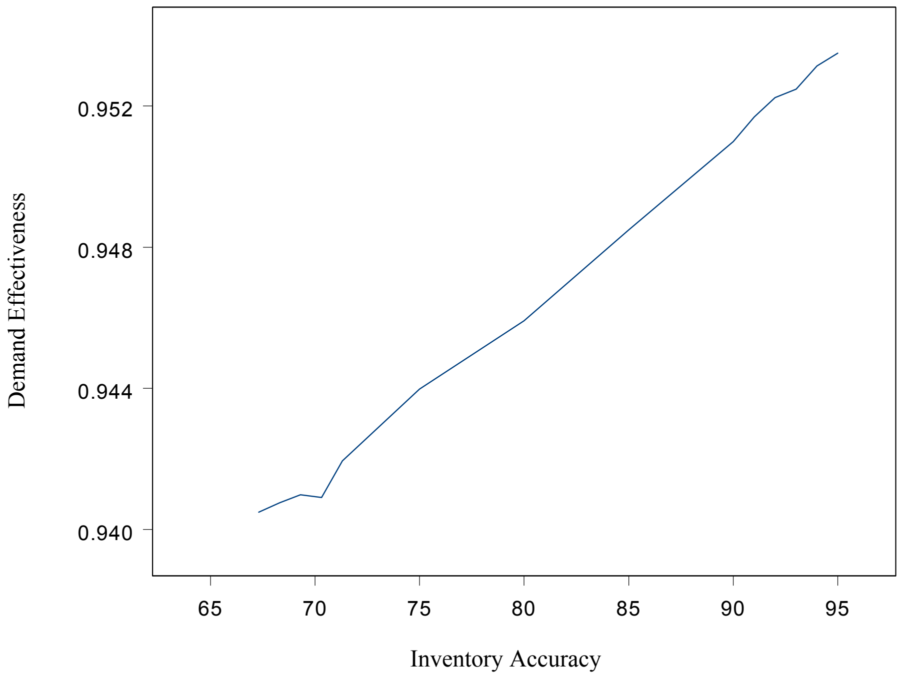
The first set of simulations was designed to analyze the effects of varying inventory accuracy on total variable costs and demand effectiveness. Inventory accuracy was incrementally raised for all magnitude of inventory record errors from the estimated level reported by STATMAN to the NAVSUP accuracy goal of 95 percent, in the manner presented in Table 4.

Table 4. Inventory Accuracy Data for Simulation Set 1

Site	Magnitude of Inventory Record Error				
	0%	$\leq$ 1%	$\leq$ 5%	$\leq$10%	>10%
1	67.31	67.31	76.92	76.92	23.08
2	68.31	68.31	77.63	77.63	22.37
3	69.31	69.31	78.33	78.33	21.67
4	70.31	70.31	79.04	79.04	20.96
5	71.31	71.31	79.74	79.74	20.26
6	75.00	75.00	82.35	82.35	17.65
7	80.00	80.00	85.88	85.88	14.12
8	85.00	85.00	89.41	89.41	10.59
9	90.00	90.00	92.94	92.94	7.06
10	91.00	91.00	93.65	93.65	6.35
11	92.00	92.00	94.35	94.35	5.65
12	93.00	93.00	95.06	95.06	4.94
13	94.00	94.00	95.76	95.76	4.24
14	95.00	95.00	96.47	96.47	3.53

The probability of negative errors remained fixed at 0.6 throughout the set. Since the magnitude of error greater than ten percent is unknown due to current data collection techniques, the simulations were run as a “best case scenario” by limiting all errors greater than ten percent to be equal to ten percent.

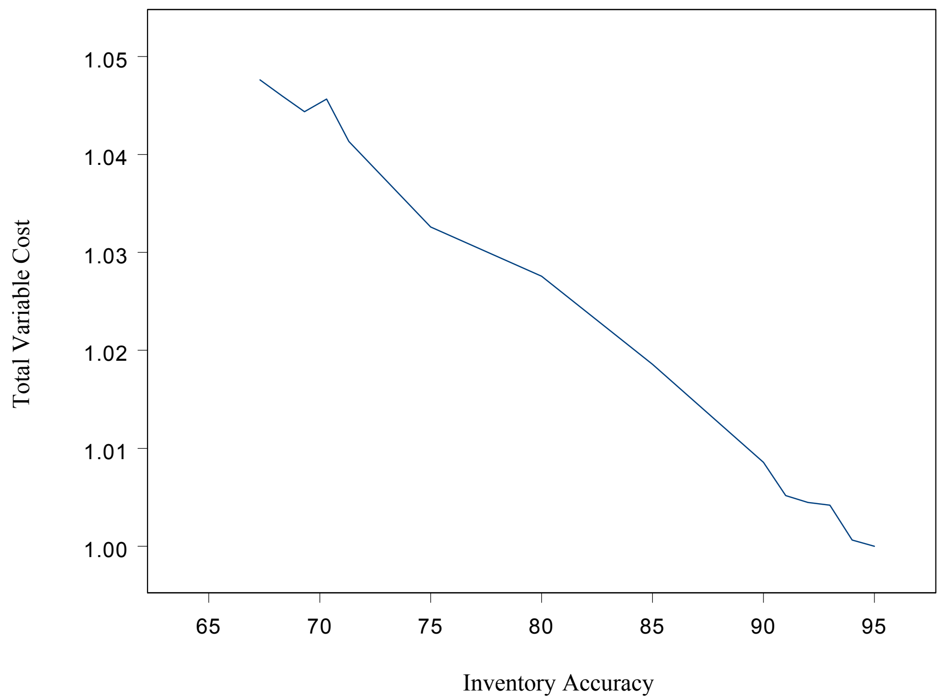
Figure 5. Demand Effectiveness versus Inventory Accuracy



Demand Effectiveness increased from 94.05 percent to 95.35 percent by increasing the Inventory Accuracy from the current level (67.31 percent) to the inventory accuracy goal (95 percent).

Figure 5 shows that system effectiveness in meeting demand increases as inventory accuracy increases. Using these results, the chosen inventory site could increase system effectiveness at least 1.3 percent if they increased inventory accuracy to the 95 percent accuracy goal.

Figure 6. Total Variable Cost versus Inventory Accuracy



Total variable cost is represented as a percent of the total variable cost relative to the 95 percent inventory accuracy goal.

Figure 6 shows that total variable costs decrease as inventory accuracy increases. This change is due to the decrease in ordering costs since holding costs remained unchanged. This analysis shows that the inventory site could require at least 4.76 percent more budget to operate at the lower inventory accuracy than if it were performing at the NAVSUP inventory accuracy goal.

As previously mentioned this set of simulations assumed a "best case scenario" by limiting all errors greater than ten percent to be equal to ten percent. Even under this favorable assumption, the cost of operating the selected inventory system for one year was 4.76 percent higher, and its demand effectiveness was 1.3 percent lower, than if the system operated at the NAVSUP 95% inventory accuracy goal.

C. EFFECTS OF VARYING INVENTORY ACCURACY ON TOTAL OPERATING COSTS

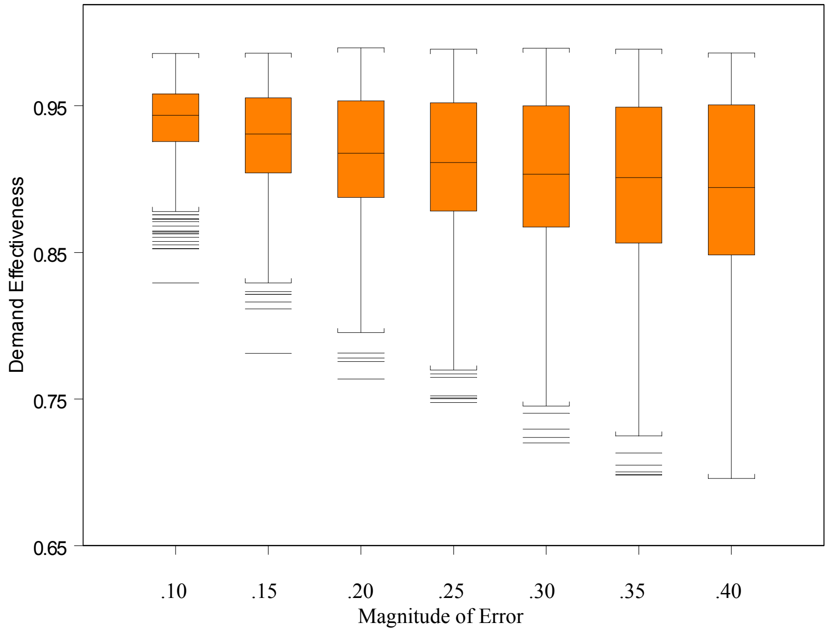
A second set of simulations was conducted to estimate the cost of increasing the demand effectiveness of the inventory system performance to the level that would be achieved by attaining the 95% accuracy goal, but by maintaining the current level of inventory accuracy. This was done by increasing the safety levels of line items until the desired demand effectiveness was achieved. It is known that increasing the safety level of all line items increases system effectiveness in a stochastic inventory system (Tersine, 1998). Equation (4) shows that increasing the safety level increases the reorder point. Raising the reorder points by 10 percent for all line items produced a demand effectiveness of 95.35 percent for the system operating below goal. However, this increase was achieved by adding 7.98 percent more inventory to the system, which would cost at least 15.95 percent more to operate than the same system operating at the NAVSUP inventory accuracy goal.

D. EFFECTS OF LARGE ERROR MAGNITUDES ON INVENTORY SYSTEM PERFORMANCE

In the first two sets of simulations a "best case scenario" was adopted in which inventory error magnitudes that fell in the "greater than ten percent" category were treated as exactly ten percent. Aggregation of these errors in STATMAN reports makes it impossible to discern the actual magnitudes of error. A third set of simulations was conducted to explore the sensitivity of results obtained in the previous two sections to this assumption.

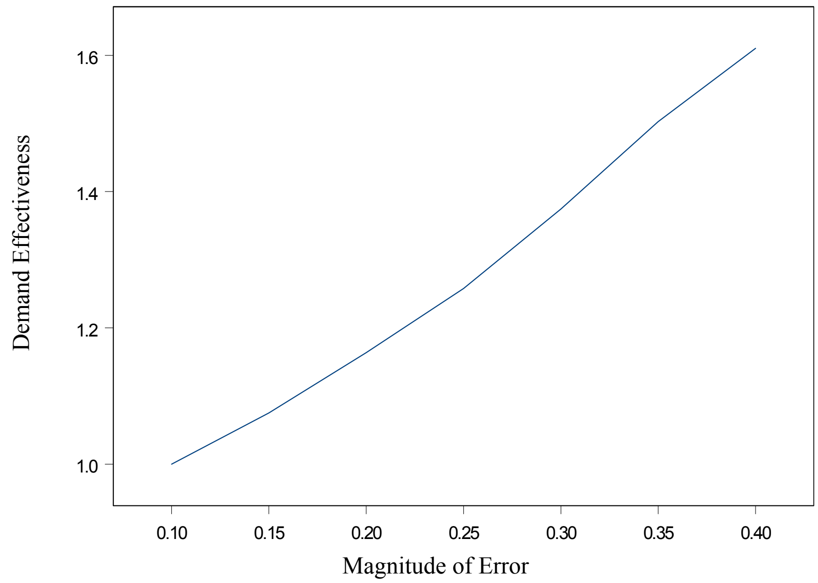
A total of seven simulations were conducted in this set. All parameters from the first set of simulations were used, with the exception of the initial shelf quantity. Shelf quantities were recalculated using variable magnitudes of error in the greater than ten percent category that ranged from .10 to .40 in increments of .05. The percentage of line items that had magnitude greater than 10 percent was 23.08. Results from this set of simulations are presented in Figures 7 and 8.

Figure 7. Demand Effectiveness versus Magnitude of Error



Magnitude of error increases were applied to all line items that were identified as having magnitude of error greater than 10 percent. For this simulation, 23 percent of the line items had magnitude of error greater than 10 percent.

Figure 8. Total Variable Cost versus Magnitude of Error



Total variable cost is represented as a percent of the total variable cost attained by Simulation 1. In Simulation 1 all line items that were identified as having a magnitude of error greater than 10 percent, were assigned a magnitude of error of exactly 10 percent.

Not surprisingly, Figures 7 and 8 show that demand effectiveness decreases and total variable costs increase as the magnitude of error increases for the selected site. In the first set of simulations a “best case” scenario revealed the total variable costs were at least 4.8 percent higher and that demand effectiveness was at least 1.3 percent lower. However, if the magnitude of error was 40 percent instead of 10 percent, total variable costs would be 65 percent higher and effectiveness 6.2 percent lower for the system operating below the inventory accuracy goal. These results suggest that reporting inventory error magnitudes in a “greater than 10 percent” category could mask substantial overruns in operating costs, or shortfalls in effectiveness, without inventory management being alerted to the problem. From Table 2 it is seen that six of the eleven FISC San Diego inventory sites had at least one sampled inventory item with a magnitude of error greater than ten percent during the third quarter of 2002. Data summarization in

STATMAN should be refined to describe the actual magnitude of error in this category more precisely.

An analysis was conducted to measure the cost of raising the demand effectiveness of the inventory system for varying levels of error magnitude. This analysis is similar to that conducted in the second simulation set; in this case the reorder points of all line items were gradually increased until the resulting demand effectiveness for the simulation with twenty percent magnitude of error matched the 94.01 percent effectiveness obtained by the system with ten percent magnitude of error. The result of this analysis is that 42.1 percent more inventory would be required for the twenty percent magnitude of error system than is required at ten percent magnitude of error. Therefore, if the magnitude of error for Site 8 were twenty percent rather than ten percent, the actual increase in total inventory cost would be 76.5 percent greater for the system performing at the inventory accuracy goal.

E. AN EVALUATION OF CURRENT INVENTORY ACCURACY GOALS

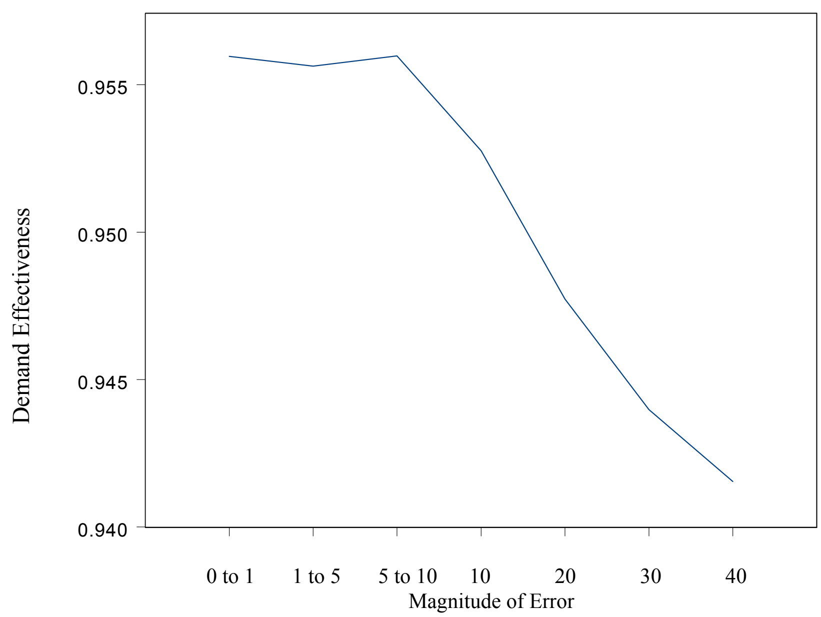
Research described in the previous section shows that operating an inventory system with inaccurate inventory records increases total variable costs and decreases demand effectiveness. It may be possible to achieve significant cost savings and increased demand effectiveness by raising the inventory record accuracy of Naval inventory sites to the 95 percent level prescribed by NAVSUP for high-demand items. However, a focus on inventory accuracy goals neglects the magnitude of inventory record errors. It was shown that the magnitude of these errors can substantially affect both cost and effectiveness for inventory systems operating at the same level of inventory accuracy

Suppose that an inventory system operates at the 95 percent inventory accuracy goal for high-demand items: to what extent can errors in the remaining 5 percent of item records affect its operation? To answer this question, a fourth set of simulations was conducted, in which the magnitudes of error for an inventory system with 95 percent accuracy were allowed to vary. Seven simulations were conducted in this set, with error magnitudes determined in the following manner:

1. Each item-error uniformly distributed between 0 and 1 percent
2. Each item-error uniformly distributed between 1 and 5 percent
3. Each item-error uniformly distributed between 5 and 10 percent
4. Each item-error set to 10 percent
5. Each item-error set to 20 percent
6. Each item-error set to 30 percent
7. Each item-error set to 40 percent.

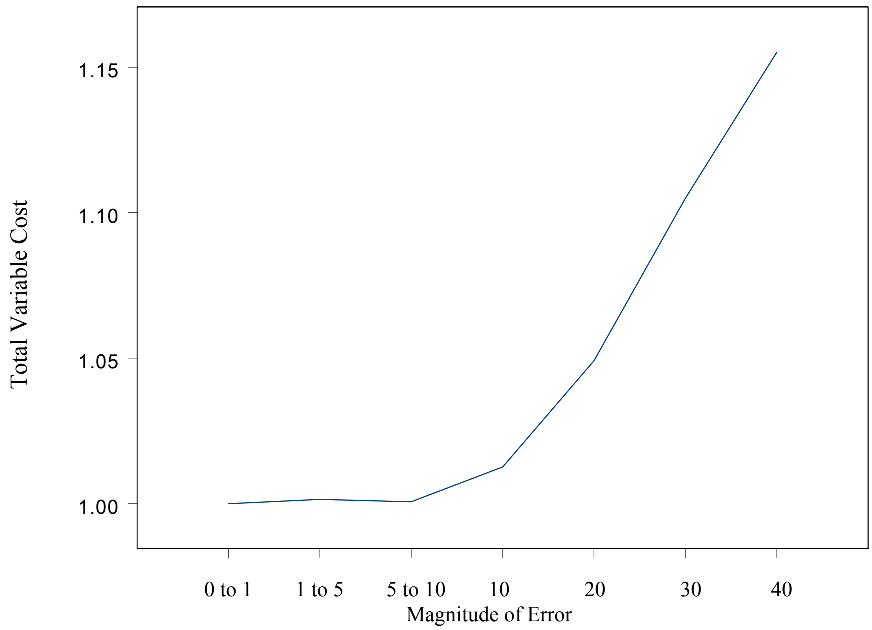
The inventory configuration was the same as that used in the simulations described in the previous section, based on 337 high-demand line items held at FISC San Diego Site 8.

Figure 9. Demand Effectiveness versus Magnitude of Error with Inventory Accuracy of 95 percent



Magnitude of error effects applied to only five percent of all line items. This shows that an inventory system can be performing at the 95 percent inventory accuracy goal and still have decreased demand effectiveness, if the magnitude of error is greater than ten percent.

Figure 10. Total Variable Cost versus Magnitude of Error with Inventory Accuracy of 95 percent



Total variable cost is represented as a percent of the total variable cost relative to the 0 to 1 magnitude of error simulation.

Results of the simulations are shown in Figures 9 and 10. It is seen that demand effectiveness and total variable costs for the system operating at the inventory goal remain almost unchanged if the magnitude of errors is less than 10 percent. However, total variable costs increase 16 percent and demand effectiveness decreases 1.5 percent when the magnitude of error in increased from less than ten percent, to forty percent. This analysis points to the inadequacy of maintaining quality control on inventory record accuracy using the inventory accuracy metric alone, without considering the magnitudes of inventory record errors.

F. EVALUATING CURRENT INVENTORY ACCURACY POLICIES

Current Navy inventory policy requires inventory accuracy officers to perform corrective actions if the estimated inventory accuracy falls below the NAVSUP goal by the tolerance levels listed in Table 2. For high-demand (Category B) material the tolerance is ten percent. Adopting a tolerance allows the system some leeway before

undertaking a burdensome activity; it is also appropriate because estimated inventory accuracy is subject to sampling variability.

To evaluate the effectiveness of this policy on the high-demand material held at Site 8 a fifth set of simulations was conducted. In section E of this chapter, the fourth simulation set focused on the extent to which errors in the remaining 5 percent of item records affect Site 8 high-demand effectiveness and total variable costs. Since the current tolerance policy allows the inventory accuracy to decrease to 85 percent, it is necessary to determine the effects that errors in the remaining 15 percent of item records would have. The error magnitudes were determined in the same manner as the fourth simulation, by applying the varying magnitude of error to the 15 percent of line items that were allowed to have inaccurate quantities.

Figure 11. Demand Effectiveness versus Magnitude of Error with Inventory Accuracy of 95 Percent and 85 Percent

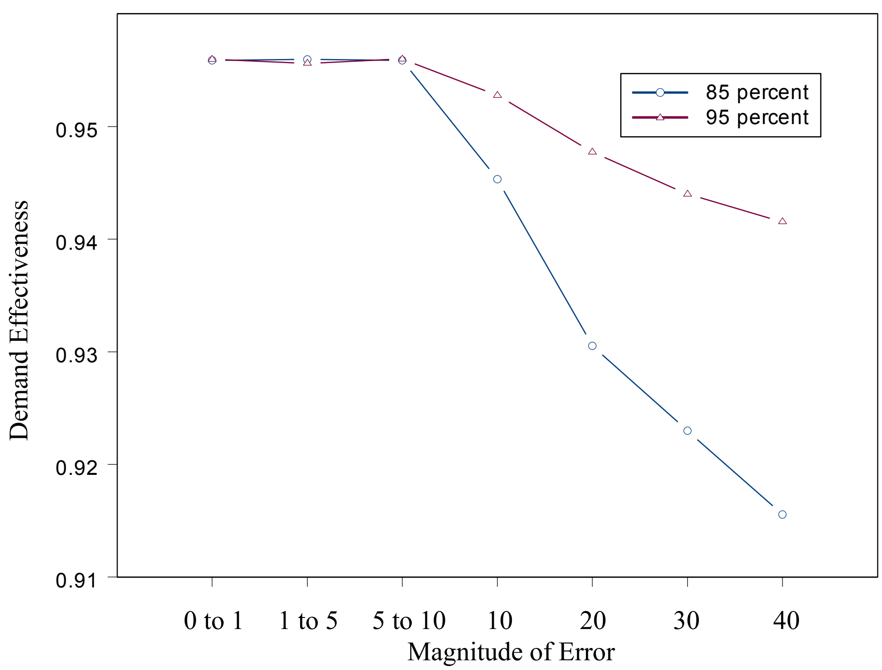
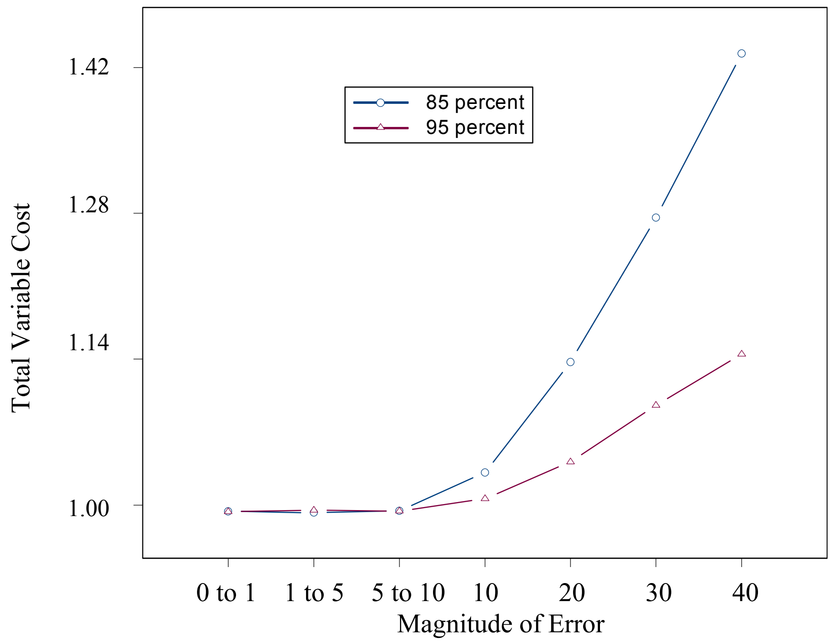


Figure 12. Total Variable Cost versus Magnitude of Error with Inventory Accuracy of 95 Percent and 85 Percent



Total variable cost is represented as a percent of the total variable cost relative to the 95 percent inventory accuracy goal with 0 to 1 magnitude of error.

Figures 11 and 12 show demand effectiveness and total variable costs at Site 8 are the same for 95 percent inventory accuracy and 85 percent inventory accuracy when the magnitude of error is less than ten percent. The purpose of performing corrective actions is to increase demand effectiveness and reduce operating costs. This suggests that performing corrective actions on an inventory system with 85 percent inventory accuracy may not be cost-effective if the error magnitudes are sufficiently small.

However, as the magnitude of error increases beyond 10 percent benefits of performing corrective actions become more pronounced. If the magnitude of error for the inventory system is forty percent, corrective action should be taken long before the inventory accuracy reaches 85 percent. Therefore, waiting until the inventory accuracy exceeds the tolerance level is detrimental to inventory system efficiency, if the magnitude of error is large.

This analysis reiterates the point that inventory accuracy and magnitude of error must both be considered in limiting the effects that inventory errors have on an inventory system. Therefore, the current inventory tolerance policy must be altered to include the magnitude of error.

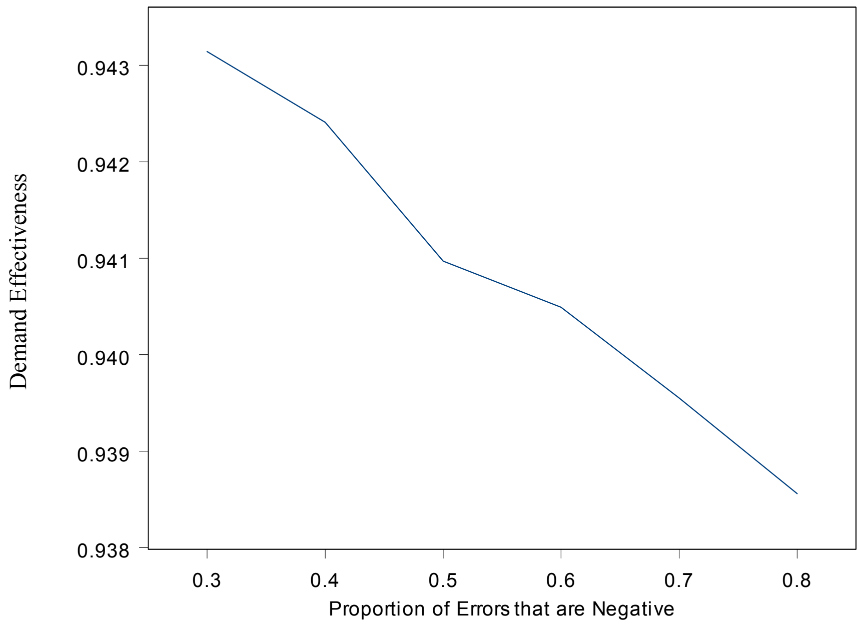
G. EFFECTS OF VARYING THE PROPORTIONS OF POSITIVE AND NEGATIVE ERRORS

All analyses presented thus far were conducted under the assumption that the proportion of inventory record errors that are negative (shelf quantity less than book quantity) is 0.6, based on STATMAN data for FISC San Diego inventory Site 8. In the final analysis presented in this thesis, the proportions of positive and negative errors were varied while holding the inventory accuracy percentages at the current operating levels of the studied partnership site. The purpose of this analysis is to provide insight into other inventory systems that do not have sixty percent of all inventory errors that are negative.

Six simulations were conducted in this set, with proportion of errors that are negative/positive determined in the following manner:

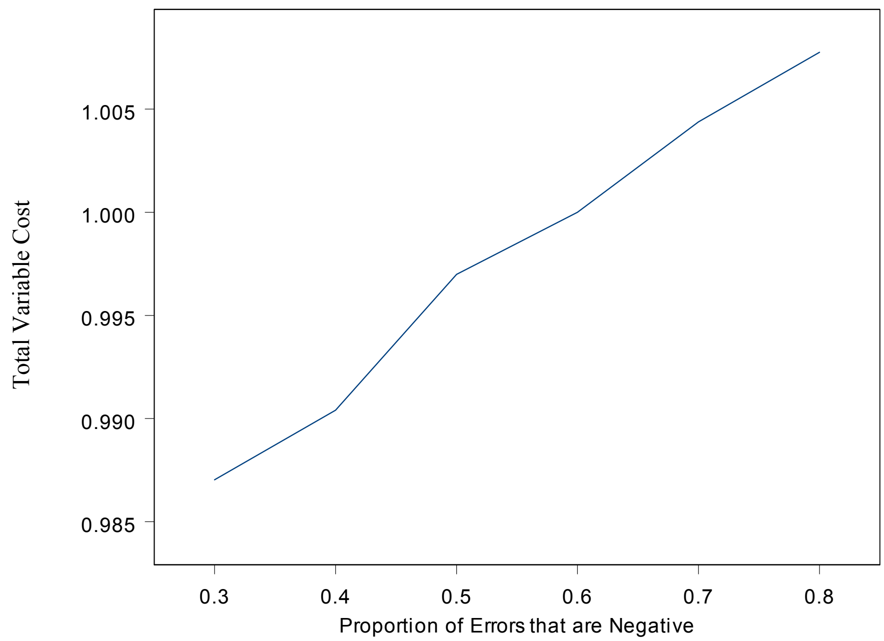
1. Each item-error uniformly distributed with 80 percent negative and 20 percent positive
2. Each item-error uniformly distributed with 70 percent negative and 30 percent positive
3. Each item-error uniformly distributed with 60 percent negative and 40 percent positive
4. Each item-error uniformly distributed with 50 percent negative and 50 percent positive
5. Each item-error uniformly distributed with 40 percent negative and 60 percent positive
6. Each item-error uniformly distributed with 30 percent negative and 70 percent positive

Figure 13. Demand Effectiveness versus Proportion of Errors that are Negative



Results of the analysis, shown in Figure 13, are consistent with expectations from inventory theory. Negative errors tend to cause an inventory system to order too late, and therefore increase the chance of a customer demand arriving when there is no material on the shelf. This behavior reduces demand effectiveness.

Figure 14. Total Variable Cost versus the Proportion of Errors that are Negative



Total variable cost is represented relative to 0.6 proportion of errors being negative.

Positive errors hold more inventory than expected, and therefore holding costs increase as the proportion of errors that are positive increase. However, simulations of the 337 high demand inventory items held at Site 8 show that the number of orders increases as the proportion of errors that are negative increase. Ordering costs in this situation overcome the associated holding costs, and total variable costs increase as the proportion of errors that are negative increase.

Therefore, if inventory errors are allowed to exist in the high demand items at Site 8, it is preferable that they be positive rather than negative.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

In this thesis it was shown that increasing the inventory record accuracy of one of the FISC San Diego partnership sites could decrease its total variable costs and increase its effectiveness in filling demands. It was also shown that inventory costs and demand effectiveness are not substantially affected by inventory record inaccuracy if the magnitude of error is less than ten percent. Inventory costs can be decreased and demand effectiveness increased by decreasing the magnitude of errors to less than ten percent for all line items.

It would be difficult to accurately determine the financial and operational impact that inventory record errors have on the Naval inventory system. Current inventory data collection techniques are designed to ensure compliance of inventory sites to NAVSUP inventory accuracy goals. Consequently, these goals do not address magnitude of error limitations and data is not collected on the magnitude of error greater than ten percent. Therefore, assumptions about the magnitude of error have to be made when comparing current operations to how the system would operate at the NAVSUP inventory goal A "best case" scenario assumption that all magnitude of errors were exactly ten percent revealed total variable costs that were at least 4.8 percent higher and demand effectiveness that was 1.3 percent lower. When this conservative assumption is relaxed it was found that the total variable costs could be as much as 65 percent higher and demand effectiveness 6.2 percent lower.

An analysis of current NAVSUP inventory accuracy goals revealed that the magnitude of error must be included to maintain effective control over the quality of inventory system records. Increasing the magnitude of error to forty percent increased total variable costs by 16 percent and decreased demand effectiveness by 1.5 percent for a system operating at the inventory accuracy goal.

Similarly, current inventory corrective actions should take the magnitude of error into consideration. The thesis research shows that performing corrective actions when the magnitude of error is less than ten percent may not be cost-effective if the inventory

accuracy goal is marginally violated. Similarly, waiting to perform corrective actions until a tolerance level is violated may be detrimental if the magnitude of errors is thirty percent.

B. RECOMMENDATIONS

The current NAVSUP inventory accuracy goal of 95 percent for high-demand (Category B) material can be effective only if the 5 percent (or fewer) of items with inaccurate inventory records are in error by less than ten percent (relative to the book quantity). It is therefore recommended that NAVSUP expand its inventory accuracy goal to require that no item have an inventory record error magnitude greater than 10 percent. Quarterly inventory accuracy reports produced by STATMAN or other software should be modified accordingly.

It should be adopted as policy that all Naval inventory sites satisfy the modified inventory accuracy goal, and that all errors with a magnitude of greater than 10 percent be reported to NAVSUP along with current quarterly inventory accuracy reports.

APPENDIX A: SOFTWARE USED FOR ANALYSIS

Inventory simulations were conducted using two JAVA programs that have been reproduced in this appendix. The hardware and software used in conjunction with these two programs is listed below.

- Hardware: IBM-compatible Micron Electronics computer with Pentium III processor operating at 667 MHz

- Software: JAVA programs were written and compiled using Borland Jbuilder 3 Professional.

- Random Numbers: Random numbers were obtained using SIMKIT. Seeds were set by using the SIMKIT congruential seed class.

A. INVENTORYMODEL

InventoryModel is the principal software module and uses the item-specific data set. This module simulates demands, orders and conducts day-to-day system operations.

```
/**
* InventoryModel
*
*    This model will perform a Monte Carlo simulation on
*    the array data to determine the effects of inventory
*    inaccuracies on system operating costs and
*    effectiveness.
**/

import java.util.*;
import simkit.*;
import simkit.random.*;

public class InventoryModel{
//main method
   public static void main (String[] args){
```

```
/**
* Simkit is used to generate the initial shelf quantities
* and demands by producing random numbers.
**/
      long seed = CongruentialSeeds.SEED[0];

/**
* The array invacc is a 5-vector of probabilities for
* inaccuracy intervals
* invacc[0] = Probability(Inventory inaccuracy = 0)
* invacc[1] = Probability(Inventory inaccuracy<0.01)
* invacc[2] = Probability(Inventory inaccuracy<0.05)
* invacc[3] = Probability(Inventory inaccuracy<0.1)
* invacc[4] = Probability(Inventory inaccuracy<1)
**/
      double [] invacc = new double[5];
      invacc[0]= 0.6731;
      invacc[1]= 0.67311;
      invacc[2]= 0.7692;
      invacc[3]= 0.76921;
      invacc[4]= 1.0;

/**
* The variable low is used as the probability that the
* inventory error is negative
**/
      double low = 0.6;

/**
* OUTPUTS for the model are effectiveness, holding cost and
* number of orders.  Effectiveness is instantiated here,
* holding cost and number of orders are instantiated
* further in the body of the model.
* Effectiveness is determined by collecting the total
* number of demands filled (effFilled) dividing by the
* total number of demands received (effDemand).
**/
      double effectiveness=0.00;
      double effDemand =0.00;
      double effFilled = 0.00;

/**
* The data frame called data is a 337 X 8 double array
* of the NIINs with operating parameters from the FISC San
* Diego partner site Category B material.
*    Column 1 = number
```

```
*    Column 2 = NIIN (without preceding zeroes)
*    Column 3 = Purchase cost per unit
*    Column 4 = Annual demand
*    Column 5 = Reorder Point
*    Column 6 = Reorder Quantity
*    Column 7 = Procurement lead time (days)
*    Column 8 = Initial book quantity (units)
**/
      double [] [] data = {
/**
*         #,    NIIN,  Cost, Dem,ROP,ROQ,  PLT, OH
**/
         {  1,  107823,  6.56,  17,  2, 26, 42.9,  5},
         {  2,  152182, 49.43, 241,  5, 20,  7.5, 22},
         {  3,  249665,  6.33, 149,  5, 15, 12.2,  9},
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         {  5,  343193,  3.43, 184, 19, 36, 37.6, 69},
         {  6,  453296,  0.31,  36,  2,  5, 20.2, 12},
         {  7,  522430,  3.86,  30,  2,  4, 24.3, 24},
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          {337,14624439, 24.25,  23,  1,  6, 15.8,  2},
       };

       double meanInterarrivalTime;
       int k = 1;
       int nsim = 1000;
       System.out.println(
          "Demands,Effectiveness,Holding Cost,Orders");

/**
* Outer Loop to simulate number of runs which is equal to
* nsim.
* For all runs nsim = 1000.
**/
       while(k<=nsim){

/**
*    totDemands = total demands received for all NIINs
*    totFilled = total demands filled for all NIINs
*    totHCost = total holding costs for all NIINs
*    totOrders = total orders for all NIINs
*    j = the NIIN number
**/
       int totDemands = 0;
       int totFilled = 0;
       double totHCost = 0;
       int totOrders = 0;
       int j=0;
```

```
/**
* Inner Loop to simulate all NIINs in data set
**/


         while(j<337){
/**
* Demands for each NIIN occur as a random variable based on
* the average number of days between demands.  The variable
* used is meanInterarrivalTime and it is obtained by taking
*  the number of days in a year and dividing by the average
* annual demand. This number is then used by Simkit to
* generate days between demands.
**/
            meanInterarrivalTime=(365/data[j][3]);
            RandomVariate rv =
               RandomVariateFactory.getInstance(
               "simkit.random.ExponentialVariate",
               new Object[]
               {new Double(meanInterarrivalTime)}, seed);
               double x;

/**
* The integer i will be incremented from 1 to 365 to
* simulate one full year of demands on the NIIN.
**/
            int i = 1;

/**
* The initial book quantity for each NIIN is taken from
* column 8 of the data array.  Initial book quantity, the
* invacc vector, and the scalar low are used by the
* ShelfGenerator model to generate the initial shelf
* quantities for each simulation.
**/
            int book =(int)data[j][7];
            ShelfGenerator newShelf =
               new ShelfGenerator(book,invacc,low);
            int shelf = newShelf.getValue();

/**
* Variable instantiation
* reorder = the reorder quantity obtained from data col 5
* eoq = the reorder quantity obtained from data column 6
* position = inventory position based on initial book qty
* daysTilArrive = variable telling when the next arrival
```

```
* of material will occur.  Initially set to a
* number that is greater than all possible
* requirement times, and will be set in a logic
* step in the body of the simulation.
* plt = procurement lead time obtained from data column 7
* daysTilDemand = random variable telling when the next
* demand will occur on the NIIN.  Initially set to 1 to
* seed the system in determining initial demands
* for all NIINs.
* demand = demand for this NIIN only
* filled = number of demands filled for this NIIN only
* orders = orders made for this NIIN only
* cost = unit purchase cost for the NIIN obtained from data
* column 3.
* holdingCost = holding cost for this NIIN is based on the
* daily holding cost rate times the shelf quantity.
**/
            int reorder =(int)data[j][4];
            int eoq = (int)data[j][5];
            int position = book;
            int daysTilArrive = 200;
            int plt =(int) Math.round(data[j][6]);
            int daysTilDemand = 1;
            int demand = 0;
            int filled = 0;
            int orders = 0;
            double cost = data[j][2];
            double holdingCost=0;

            do{
/**
* Daily decrementing the number of days until an arrival
* and days until a demand occur.
**/
               daysTilArrive--;
               daysTilDemand--;

/**
* Logic step to determine if the NIIN needs to have an
* order placed by determining if the book quantity is at or
* below the reorder quantity.  If it is, an order is
* placed, the days until the requisition is received is set
* to the procurement lead time, the number of orders
* increases by one and the inventory position is increased
* by the number of items requisitioned which is equal to
* the eoq (reorder quantity).
**/
```

```
               if(position<=reorder){
                  daysTilArrive=plt;
                  orders++;
                  position=position+eoq;
               }

/**
* Logic step to determine if a requisition arrival has
* occurred.  If the days until an arrival equals zero the
* book and shelf quantity are increased by the reorder
* quantity.
**/
               if(daysTilArrive==0){
                  book=book+eoq;
                  shelf=shelf+eoq;
               }

/**
* Logic step to determine if a demand should occur.  If
* the days until a demand is less than 1, Simkit will
* generate another demand and give the days until the
* demand should occur.  The number of demands will be
* incremented by one.  Imbedded in the step is the
* determination if the demand can be filled.  If the shelf
* quantity is greater than zero the demand is filled, the
* book and inventory position quantities are decremented by
* one, the shelf quantity is decremented by one, and the
* number of demands filled is incremented by one.  If the
* shelf quantity is not greater than zero there is not
* enough material on the shelf to fill order.  The
* inventory position is reset by subtracting the
* book quantity.
**/
               if(daysTilDemand<1){
                  x=rv.generate();
                  daysTilDemand=(int)x;
                  demand++;

                  if(shelf>0){
                     book--;
                     position--;
                     shelf--;
                     filled++;
                  }
                  else{
                     position = position -book;
```

```
                }
             }


          holdingCost=holdingCost+(.23*shelf*cost/365);

          i++;
          }while(i<=365);

         totDemands=totDemands+demand;
         totFilled=totFilled+filled;
         totHCost=totHCost+holdingCost;
         totOrders=totOrders+orders;

/**
* This concludes the one year simulation of this NIIN.  The
* next NIIN data is obtained by incrementing the integer j.
**/
         j++;
         }

         effDemand = totDemands;
         effFilled = totFilled;
         effectiveness = effFilled/effDemand;

/**
* The seed for the random number generator must be changed
* to ensure the same set of random numbers are not
* obtained.
**/
         seed=seed+1;


System.out.println(totDemands+","+effectiveness+
               ","+totHCost+","+totOrders);

/**
* END of Inner Loop
**/
      k++;
      }

/**
* END of Outer Loop
**/
   }
}
```

B. SHELFGENERATOR

The ShelfGenerator program is used in conjunction with the InventoryModel to determine the initial shelf quantity based on the inventory accuracy and the initial book value.

```
/**
* ShelfGenerator
*
* This program will take an initial book value - x
* and the appropriate inventory accuracy - invacc
* and will generate a shelf inventory value
**/

import java.util.*;
import simkit.*;
import simkit.random.*;

public class ShelfGenerator{

// instance variables

   private long seed = System.currentTimeMillis();
   private int shelf;
   private int book;

/**
* This model uses the invacc vector from the InventoryModel
* to create the initial shelf quantity.  A random number u
* is generated and compared to the invacc vector to
* determine which category of inaccuracy the NIIN will fall
* into.
*
* If the random number u is below invacc[0] then there is
* no inventory inaccuracy and the shelf quantity will equal
* the book quantity.
*
* If the random number u is above invacc[0] and below
* invacc[1] then the inventory inaccuracy is greater than
* zero percent but less than one percent inaccurate.
* Parameters1 sets the endpoints for this category and a
* random variate rv1 is selected using a uniform
* distribution between the parameters1 endpoints.  This
* random variate is multiplied by the book quantity to
* determine what the magnitude of error is.  A third random
* variate y is drawn and compared to the proportion of
* errors that are negative (low).  If y is less than low,
```

```
* the shelf quantity is obtained by subtracting the
* magnitude error from the book quantity.  If y is greater
* than low the magnitude is added to the book quantity.
*
* Similarly, the inventory accuracies from one to five
* percent, and five to ten percent use parameters2 and
* parameters3 to determine the shelf quantity by perturbing
* the book quantity.
*
* Finally, if the random number u is greater than invacc[3]
* the magnitude of the inaccuracy is unknown.  For most
* models the magnitude of inaccuracy is held at ten percent
* so the magnitude of error is determined by multiplying
* ten percent by the book quantity.  The shelf quantity is
* then obtained by adding or subtracting the quantity using
* the random variable y as before.
*
* The shelf quantity is then returned to the
* InventoryModel.
**/

     private Object[] parameters1=new Object[]
          {new Double(0.000), new Double(0.01)};
     private Object[] parameters2=new Object[]
          {new Double(0.01),new Double(0.05)};
     private Object[] parameters3=new Object[]
          {new Double(0.05),new Double(0.1)};

     private RandomNumber u =
          RandomNumberFactory.getInstance(
          "simkit.random.PooledGenerator",new long[]
     {System.currentTimeMillis(),System.currentTimeMillis()
          % 12345L});
     private RandomVariate rv1 =
          RandomVariateFactory.getInstance(
          "simkit.random.UniformVariate",parameters1,seed);
     private RandomVariate rv2 =
          RandomVariateFactory.getInstance(
          "simkit.random.UniformVariate",parameters2,
          seed);
     private RandomVariate rv3 =
          RandomVariateFactory.getInstance(
          "simkit.random.UniformVariate",parameters3,
          seed);

     private double [] accuracy;
     private double low;
```

```
    private int upDown;
    private double y;
    private double z;
    private double z1;


//constructor method

/**
* The constructor takes input from the InventoryModel and
* makes a new shelf generator.
**/
   public ShelfGenerator(int x, double[] inv, double lo){
      book = x;
      accuracy = inv;
      low = lo;
   }

//instance methods

   public int getValue(){
      y=1+u.draw();
      if(y<low){
         upDown = -1;
      }
      else{
         upDown = 1;
      }
      z=1+u.draw();

      if(z<accuracy[0]){
         shelf = book;
      }
      if(z<accuracy[1]){
         z1=rv1.generate()*(-1);
         shelf = (int)(book + (book*upDown*z1));
      }
      if(z<accuracy[2]){
         z1=rv2.generate()*(-1);
         shelf = (int)(book + (book*upDown*z1));
      }
      if(z<accuracy[3]){
         z1=rv3.generate()*(-1);
         shelf = (int)(book + (book*upDown*z1));
      }
      else{
         shelf=(int)(book+ (book*upDown*.1));
```

```
        }
        return shelf;
    }
}
```

LIST OF REFERENCES

Daeschner, W., *Costs of Operating an Inventory System with Inaccurate Records.* Master's Thesis. Naval Postgraduate School. Monterey, California. June 1968.

Department of Defense Instruction 4140.39, *Procurement Cycles and Safety Levels of Supply for Secondary Items*, 17 July 1970

Department of Defense, *Supply System Inventory Report*, 30 September 2000

Department of the Navy, *FY 2003 Department of Navy Budget*, February 2002

Devore, J., *Probability and Statistics*, Fifth Edition, Duxbury Thomson Learning, 2000

General Accounting Office (GAO), *Navy Inventory, Parts Shortages Are Impacting Operations and Maintenance Effectiveness,* GAO-01-771, pp.1-5, July 2001

General Accounting Office (GAO), *Executive Guide: Best Practices in Achieving Consistent, Accurate Physical Counts of Inventory and Related Property*, GAO-02-447G, pp. 5-23, March 2002.

Hadley, G. and Whitin, T., *Analysis of Inventory Systems*, Prentice-Hall, Englewood, N.J., 1963

Navy Fleet Material Support Office (FMSO), *Statistical Accuracy Techniques and Measurements Analysis (STATMAN) Users Manual*, March 1994

Navy Fleet Material Support Office (FMSO), *Uniform Automated Data Processing System (UADPS) Users Manual*, UM-02, Revision 1, 19 June 1991

Naval Supply Systems Command Publication 485 (NAVSUP), *Naval Supply Procedures*, October 1997.

Naval Supply Systems Command Publication 553 (NAVSUP), *Inventory Management*, June 1992.

Naval Supply Systems Command Publication 723 (NAVSUP), *Navy Inventory Integrity Procedures*, 2000.

Raman, A., DeHoratius, N., and Ton, Z., "The Achilles' Heel of Supply Chain Management", *Harvard Business Review*, pp. 35-36, May 2001.

Rinehart, R., "Effects and Causes of Discrepancies in Supply Operations," *JORSA*, Volume 8, p. 4, 1960.

Schrady, D., *On Inventory Record Accuracy*, Naval Postgraduate School, NPS 55SO 8032A, March 1968.

Tersine, R., *Principles of Inventory and Materials Management*, Fourth Edition, pp. 492-553, Prentice-Hall, 1998.

Titmuss, K., "Inventory Accuracy, The First Step to Successful Supply Chain Management", paper presented at the South African Production and Inventory Control Society Conference, Durban, South Africa, June 2001.

Wilson, G., *Evaluation of Several Methods of Scheduling and Conducting Physical Inventories.* Master's Thesis. Naval Postgraduate School, Monterey, California. December 1968.

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